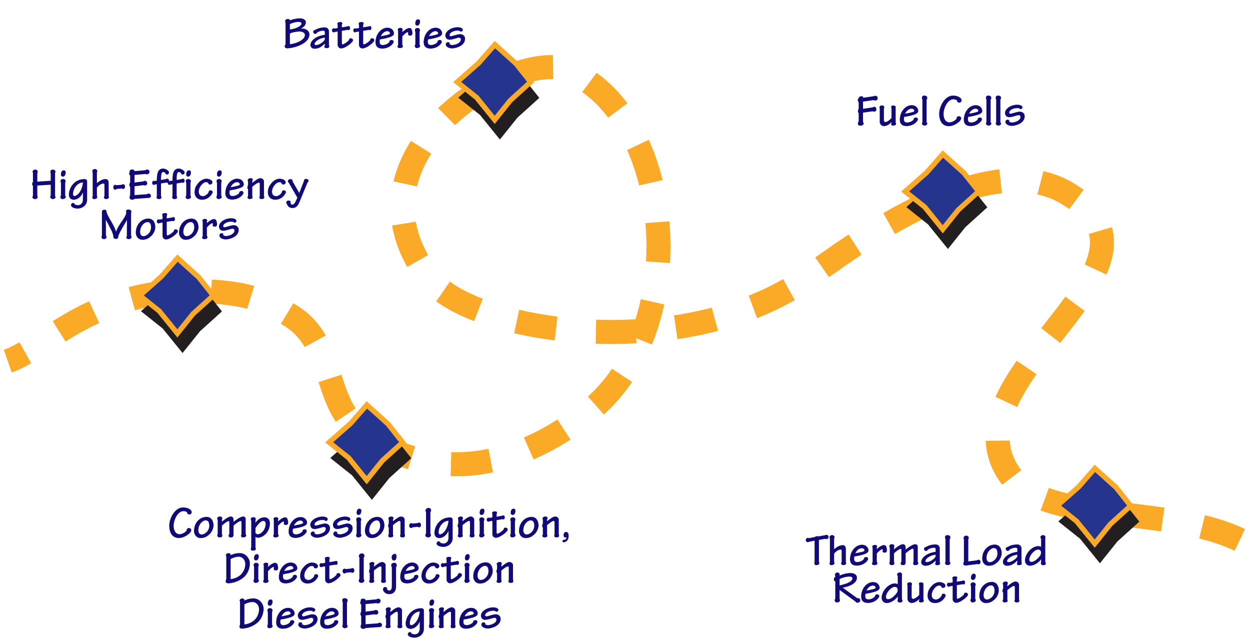
Cooperative Automotive Research for Advanced Technology

Snapshots of CARAT Projects



January 1999

Office of Advanced Automotive Technologies, Office of Transportation Technologies
Energy Efficiency and Renewable Energy, U.S. Department of Energy

Publishing support services provided by the Information and Publishing Division of Argonne National Laboratory (http://www.ipd.anl.gov).

Foreword

These Cooperative Automotive Research for Advanced Technology (CARAT) “Snapshots” are presented to give you a preview of the technologies that could, in the next decade or so, be engineered for the automobiles we drive. CARAT takes the most promising ideas from small businesses and universities, funds the development from a bench-scale to an engineering-scale prototype, and then marries the concept with a manufacturer or supplier having the know-how and resources to take the concept to market. CARAT provides a pathway to develop and validate innovative, technically advanced components and subsystems through a three-phase program of research and development. We believe that CARAT will channel the creativity and resourcefulness of the small business and academic communities to help remove the technology barriers blocking the viability of promising technologies.

The technology snapshots describe the challenge, the concept, and the benefits of 26 Phase I projects. The CARAT program encompasses 16 topic areas; of these, we funded projects in topic areas 1 through 10 and 16 (no projects were funded in topic areas 11 through 15). When Phase I draws to a close, the concepts will be validated and the results will become apparent. Industry and government representatives will discuss the merits and the potential of these projects. Some of the projects will proceed to Phase II, in which an engineering prototype will be built to meet specific performance targets, and a preliminary economic analysis will be completed to assess the technology’s potential to meet high-volume, low-cost fabrication targets. During Phase III, the participants who are selected will, with the help of an industry partner, optimize performance, packaging, and manufacturability; install the components or subsystem into a vehicle (or system) for testing and evaluation; and perform a rigorous manufacturability and cost analysis.

The success of the CARAT program will ultimately be judged by how these technologies are received by the automotive industry. Will the vehicles in which they are installed perform more effectively, more reliably, and at lower cost than their conventional counterparts? This will be the final test. I hope you enjoy this preview of the CARAT technologies.

Pandit G. Patil, Director
Office of Advanced Automotive Technologies
Office of Transportation Technologies
Energy Efficiency and Renewable Energy

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Topic 1

Reduction of Thermal Load in Passenger Compartments

The air-conditioning system requires a greater share of a vehicle's power than any other accessory. The organizations funded under this topic are working to develop a means to significantly reduce the thermal loads on the passenger compartment in light-duty vehicles. The goal is to develop alternative or improved technologies to reduce the energy consumed by the air-conditioning system by decreasing the cooling load by more than 30%. This reduction can be achieved by improving glazing material, using special coatings or paint, improving insulation, changing vehicle body design, or decreasing thermal losses from the passenger compartment.

Topic Area 1

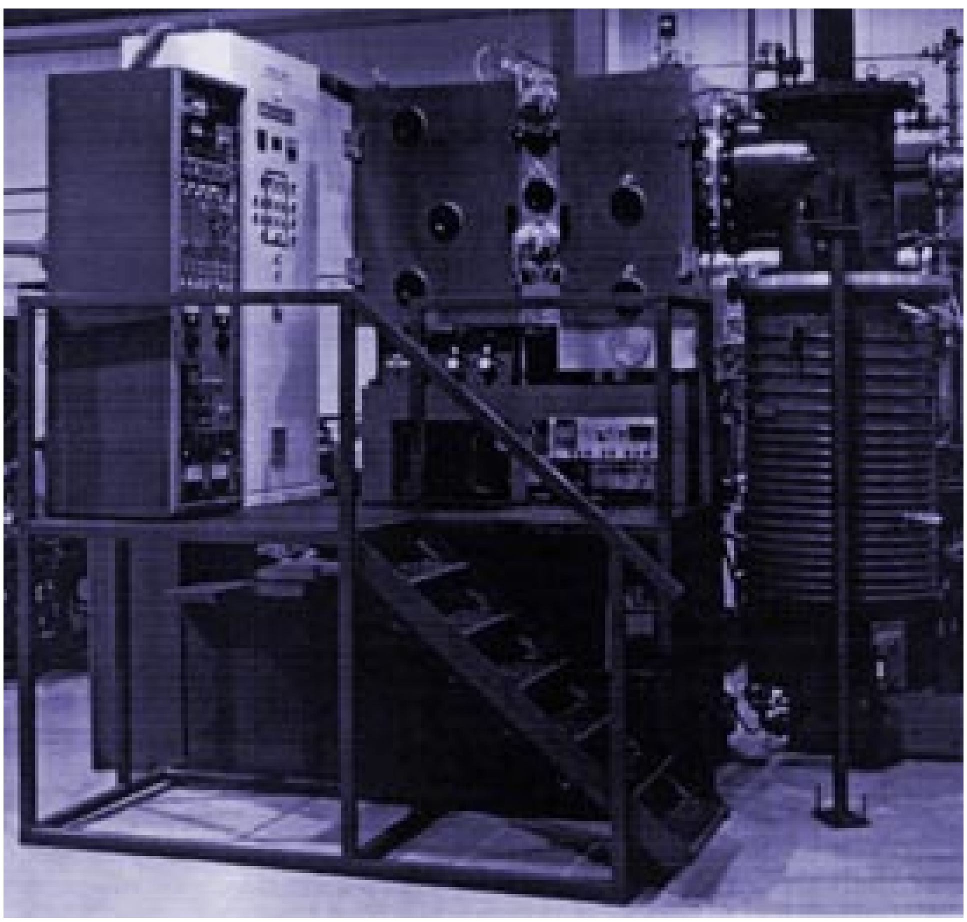
New Higher-Performance, Low-Cost Selective Solar Radiation Control Coatings

Objective

Selective Solar Radiation Control (SSRC) coatings, which transmit visible light but reflect infrared radiation, can decrease the heat load into vehicles by up to 50%, increasing passenger comfort and providing better fuel economy. Today, such coatings are expensive and are only available on luxury vehicles.

The purpose of this project is to develop higher-performance SSRC coatings at a much-reduced cost on thin, flexible polymer webs that can be laminated to the vehicle windows or deposited directly on the window glass. During Phase I, we will design, fabricate, and optimize new prototype SSRC coatings on a small scale, demonstrate the technical performance of these coatings, and estimate the large-scale economic advantage of the new manufacturing process over present technology.

Energy Conversion Device's Pilot Roll-to-Roll MPECVD Thin-Film Deposition Machine



Energy Conversion Devices, Inc.

1675 W. Maple Rd.
Troy, MI 48084

Contact

Tim Ellison, PhD
(248) 362-4780
Fax (248) 362-0012

Technical Challenge

The challenge to successfully developing this technology will be to demonstrate that ECD's new Microwave Plasma-Enhanced Chemical Vapor Deposition (MPECVD) technology can be successfully combined with sputtering to deposit thin metallic layers and fabricate high-performance multilayer coatings. Good adhesion between layers and ruggedness of the device must also be demonstrated. Alternatively, we may demonstrate that a high-performance coating can be designed and fabricated without the use of silver metallic layers.

Technical Concept/Approach

ECD has developed a proprietary high-speed MPECVD technology that can deposit high-quality dielectric coatings at about ten times the rate of sputtering technology, which is currently used to deposit SSRC coatings. ECD will use its MPECVD pilot thin-film deposition machine (see figure) to demonstrate the feasibility of depositing high-performance SSRC coatings onto thin polymer webs in a roll-to-roll process.

Status

The ability of ECD's new MPECVD technology to deposit high-quality, uniform dielectric, optical-quality coatings has already been proven; however, the technology has not yet been incorporated into an SSRC device.

Benefits

The commercialization of the products developed during this effort will allow SSRC coating to be mass produced at significantly lower cost and will lead to widespread use of SSRC coatings for automotive applications. These coatings will reduce the heat load into cars by more than 50% and, consequently, reduce the cooling load for vehicles (typically 60–90% of the auxiliary power load), leading to increased passenger comfort and better fuel economy.

Topic Area 1

Microclimate Seating System for Cooling and Heating

Objective

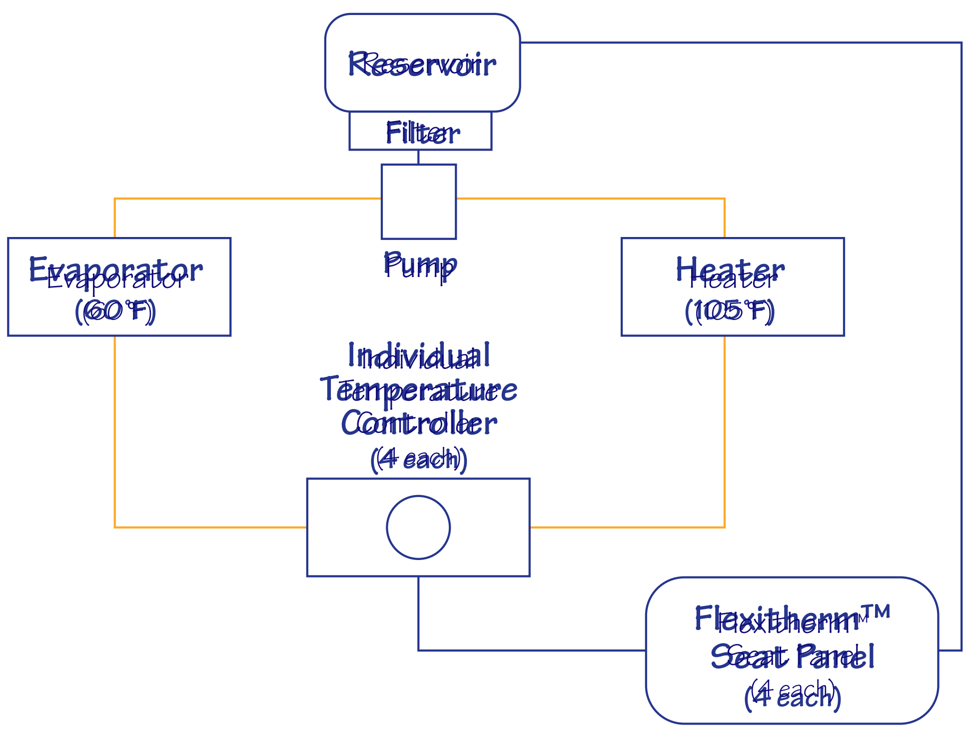
Our objective is to construct a prototype closed-loop cooling/heating subsystem by using our liquid-based heat-exchange Flexitherm™ technology. This prototype will demonstrate the effects of cooling and heating on a passenger sitting on a car seat containing the Flexitherm™ subsystem (see figure). These effects are particularly critical during the initial cool-down/warm-up period in a heat/cold-soaked vehicle.

Technical Challenge

The technical challenges to successfully implementing the improved heating/cooling seating system are designing and constructing an individual control subsystem, including valves, and supplying a source of heating and cooling to heat-exchange panels.

Technical Concept/Approach

We have built prototype Flexitherm™ panels and installed them in cushions that were placed on the outer vertical and horizontal surfaces of an automobile seat, in direct contact with the passenger. The next-generation prototype, to be developed under the CARAT grant, will advance the concept in several ways: each unit will (1) be built into a car seat, (2) have individual bias controls, and (3) be able to demonstrate varying degrees of heating and cooling.



Life Enhancement Technologies, Inc.
10866 Wilshire Blvd.
Suite 970
Los Angeles, CA 90024

Contact
Simon Jay
(310) 441-4904
Fax (310) 475-1368

Benefits

This working model will demonstrate that our liquid-based heat-exchange Flexitherm™ technology can be used in a cooling/heating subsystem as a major component in a new, more efficient automotive HVAC system.

Topic 2

Reduction of Energy Consumption by Power Accessories

Power accessories in light-duty vehicles significantly increase the energy demand for non-powertrain applications. The organizations funded under this topic are working on ways to significantly reduce the energy consumption of power accessories and systems (e.g., steering, braking, engine cooling, lighting, window regulators, windshield wipers, and locks) in passenger cars. The goal is to reduce the energy consumption of power accessories for a baseline midsize passenger car by 40%. This reduction can be achieved by incorporating higher-efficiency devices or by using more sophisticated controls to optimize the operating cycle.

Topic Area 2

Vehicle Magnetic Air Conditioner Technology

Objective

The project objectives are (1) to find the most appropriate magnetic refrigerant for use in a vehicle magnetic air conditioner (VMAC); (2) to find the best permanent magnet material and magnet configuration for use in the VMAC; (3) to determine the best heat-transfer code, mechanical configuration (rotary, reciprocating, or other) and other operating parameters (frequency and fluid flow rate) of the VMAC; and (4) to determine whether the goals for the weight, cooling capacity, and energy efficiency of the VMAC can be achieved.

Technical Challenges

The key challenges to successfully developing the VMAC include improving magnetic refrigerant materials, using better high-strength permanent magnets, and optimizing the heat transfer mode and mechanical configuration.

Technical Concept/Approach

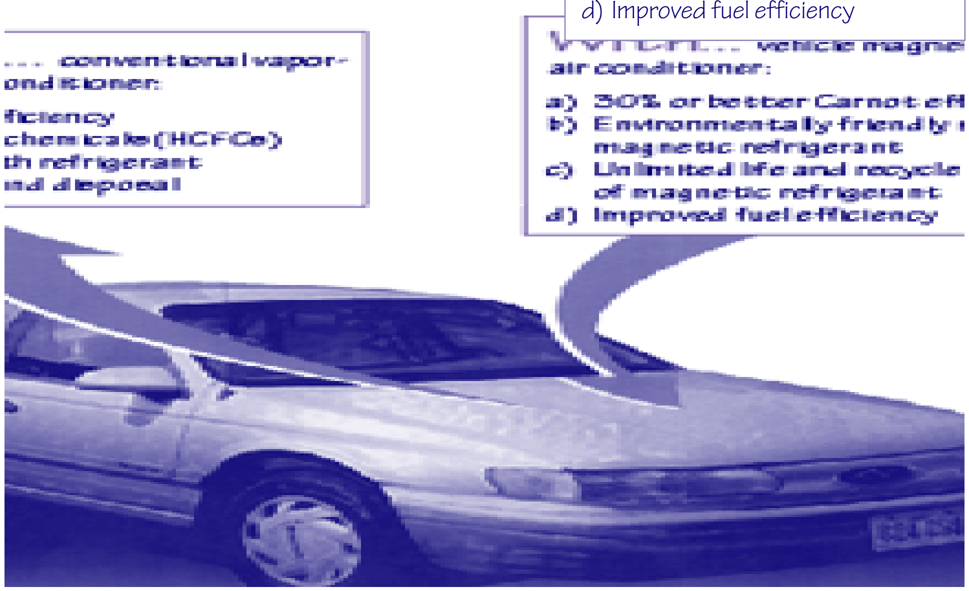
Vehicle magnetic air conditioner technology is a challenging application for magnetic refrigeration because a large temperature span, low weight, low cost, and high efficiency are all required simultaneously.

Replace... conventional vapor-cycle vehicle air conditioner:

a) Low Carnot efficiency
b) Uses harmful chemicals (HCFCs)
c) Difficulties with refrigerant replacement and disposal

With... vehicle magnetic air conditioner:

a) 30% or better Carnot efficiency
b) Environmentally friendly solid magnetic refrigerant
c) Unlimited life and recycle value of magnetic refrigerant
d) Improved fuel efficiency



Iowa State University Center for Rare Earths and Magnetics
Ames, IA 50011-3020

Contact
Karl A. Gschneidner, Jr.
(515) 294-7931

Our development approach involves six steps. First, we will obtain the specifications of a VMAC, including size, weight, cooling capacity, operating conditions, output air temperature and humidity, safety, energy efficiency requirements, and cost. Second, we will optimize the composition and parameters of the magnetic refrigerant material to meet the VMAC performance goals in magnetic fields attainable by the various permanent magnet configurations. Selected magnetic materials will be prepared, and their magnetocaloric properties will be confirmed. Third, we will determine a permanent magnet material composition and its configuration to meet the VMAC and magnetic refrigerant requirements. We will assemble and test a permanent magnet array to verify the predicted magnetic fields. Fourth, we will optimize the heat-exchange mode, operating parameters, and mechanical configuration of the VMAC to maximize energy efficiency and to meet the weight and vehicle cooling capacity requirements. Fifth, we will perform bench-top refrigerator tests with the new magnetic refrigerants to verify predicted behavior under actual conditions expected for a VMAC. Sixth, we will perform a scaling analysis and choose the most promising designs, which simultaneously consider the solid magnetic refrigerant material, the permanent magnet material and configuration, and the mechanical design and operation of the VMAC.

Status

Magnetic air conditioning offers the potential for high efficiency because the compression-expansion part of the vapor-cycle refrigeration is replaced by the magnetizing and demagnetizing of a magnetic material, which is essentially dissipation free, thus approaching 100% Carnot efficiency. The two recently achieved milestones are the proof-of-principle laboratory-demonstration magnetic refrigerator and the discovery of a new family of giant magnetocaloric-effect magnetic materials by the Iowa State University/ Astronautics Corporation of America team.

Benefits

The VMAC is expected to be 30% more energy efficient than current vapor-cycle devices. Using the VMAC will increase fuel efficiency and eliminate the need for volatile liquid chemical refrigerants, such as the hydrochlorofluorocarbons (HCFCs) currently used in vapor-cycle air conditioning.

Topic Area 2

High-Efficiency Motor for Vehicle Power Accessories

Objective

The objective of this project is to refine the patented Segmented Electromagnetic Array (SEMA) technology so that high-efficiency electric motors can be produced to provide accessory power in electric vehicles (EVs) and hybrid electric vehicles (HEVs) and yet meet automotive cost targets. The focus of this project is on the delivery of an 8.5-kW motor to drive the air conditioning compressor in an EV. A major U.S. automotive company is providing the technical specifications for this application. An important goal of this three-phase project is to use a SEMA motor to drive the air conditioning compressor in a prototype EV to prove the motor's performance and reliability.

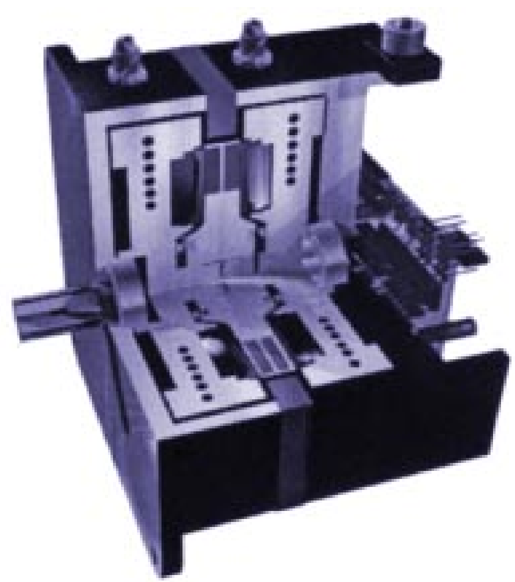
Technical Challenge

Motor cost is the primary obstacle because the automotive market is so competitive. Because of efficiency requirements and size limitations, the expense of the material to build this accessory motor is a significant constraint. The accessory motor module will, however, provide an opportunity to reduce overall system cost by integrating the control and power electronics into the motor housing (see figure). Costs could be cut in the future by manufacturing the motor as an integral part of the vehicle accessory (e.g., air conditioning compressor and motor as a single unit). Manufacturing and material cost analyses will be performed to determine the production costs at automotive volumes.

Technical Concept/Approach

Our approach will involve selecting the optimum motor and controller design to meet the air conditioning compressor requirements. Finite-element analysis (FEA) of thermal, magnetic, and electrical models will be used in this determination. In addition, scientists from Oak Ridge National Laboratory (ORNL), under separate funding, will help develop and analyze electronic controls and power electronics.

On the basis of these analyses, a single motor and integrated controller design will be selected for prototype construction and testing. Emphasis will be placed on integrating electronics into the motor module. In future phases of this CARAT effort, VCS will construct, test, and install additional prototype motors and electronics in a prototype EV for further testing.



Visual Computing Systems Corp.
9540 Highway 150
Greenville, IN 47124

Contact
Roy Kessinger
(812) 923-7474

Status

Technical specifications are being gathered for an air conditioning compressor drive motor and other potential accessory drive applications.

Benefits

Using SEMA technology will significantly cut power losses in automotive accessories. As EV and HEV technology becomes more prevalent, the importance of high-efficiency motors will increase. A single EV/HEV will require many electric motors. The results of this research effort will include a process by which a family of high-efficiency accessory motors, ranging in size from < 1 kW to > 8.5 kW can be mass produced. Therefore, successful integration of SEMA technology into the EV/HEV will yield substantial energy savings while simplifying vehicle design and reducing recurring and non-recurring costs.

Topic 3

Low-Cost, Compact, High-Efficiency Traction Motor for Electric Vehicles/Hybrid Electric Vehicles

Alternating current (AC) traction motors promise to provide high-efficiency electric propulsion over wide power and speed ranges, but improvements in the cost and power density of these motors are needed. The organizations funded under this topic are working to design and develop an advanced AC traction motor controller system for automotive use. The motors developed must offer significant reductions in cost and weight; improve energy management, emissions, and control of EVs/HEVs; be suitable for both parallel and series hybrid powertrains; and allow affordable high-volume manufacturing.

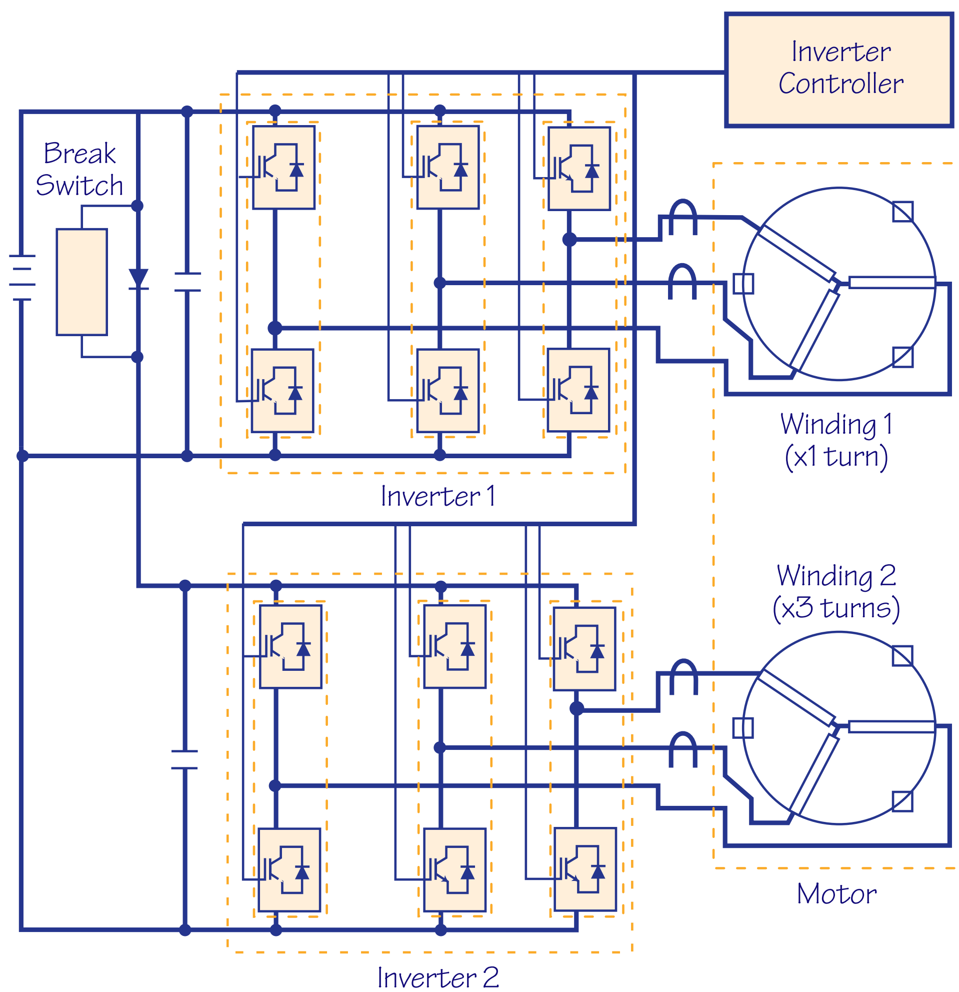
Topic Area 3

Dual-Speed Range Induction Drive Train for Electric and Hybrid Electric Vehicles

Objective

The objective of this project is to design and develop a low-cost, high-efficiency drive train for electric and hybrid electric vehicles.

The Phase I efforts will include the development of a breadboard 12.5-horsepower (hp), dual-speed, range induction traction motor and electronic drive unit. The reduced-horsepower breadboard unit will be tested to validate the efficiency and cost gains of the dual-speed range drive train over conventional, single-speed range drive trains. Validation testing will be conducted using SatCon's dynamometer facility. A full 100-hp version of the drive train will be developed during Phase II; this version will be installed in a vehicle and made available for testing and evaluation by Chrysler, Ford, and General Motors.



SatCon Technology Corp.
161 First St.
Cambridge, MA 02142

Contact
Kevin Donegan
(617) 349-0941

Technical Challenge

The challenge is to design the drive train to have higher efficiency and lower costs than those of current technologies.

Technical Concept/Approach

SatCon will design a new drive train for use with EVs and HEVs. The unique aspect of our proposed design is a dual-wound induction traction motor (see figure). The dual windings are optimized for two different rpm points across the speed range. Having multiple optimal efficiency points across the speed range creates an efficiency "sweet spot." Because the output power is generated from both windings, the electronic drive does not require as much silicon area for transistors as a drive for a conventional, single-winding traction motor. Thus, the cost of the electronic drive is also reduced.

Status

SatCon has completed a topology diagram and investigated which motor to purchase and rewind. We are also exploring the control regime for the CARAT concept.

Benefits

Low-cost electric drive trains will allow EVs and HEVs to compete in the market with conventional vehicles. The higher efficiency of this drive train will conserve natural resources and provide drivers of EVs and HEVs with a longer range between fill-ups.

Topic Area 3

Switched Reluctance Motor Drive for Electric and Hybrid Electric Vehicles

Texas A&M University Center for Advanced Vehicle Systems

Department of Electrical Engineering

College Station, TX 77843

Contact

M. Ehsani, PhD, PE, F. IEEE

(409) 485-7582

ehsani@ee.tamu.edu

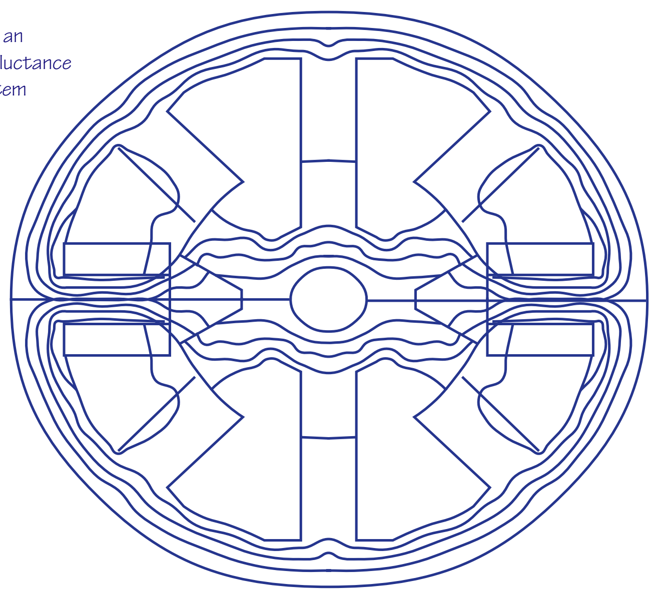
Objective

In this project, we will develop, design, and build a test bench-scale switched reluctance motor (SRM) drive, specifically suited for EV and HEV applications. We will further demonstrate our theoretically predicted results that the SRM drive is more efficient, more compact, more robust, and less expensive than other motor drive technologies that have been considered for EV and HEV propulsion applications.

Technical Challenge

Vehicle dynamics requires extended-speed, constant-power operation from the propulsion system in order to meet the vehicle's operating constraints (e.g., initial acceleration and gradeability) with minimum power. However, the importance of vehicle dynamics in designing a propulsion system has been overlooked in conventional designs. Our team at Texas A&M was the first to point out the optimal torque-speed profile of the vehicle's electrical propulsion system, as dictated by the vehicle's dynamics. Generating the optimal torque-speed profile through the vehicle's propulsion system is extremely important, because it reduces the cost by reducing the system power ratings.

Diagram Showing an 8-6 Switched Reluctance Motor Drive System



Technical Concept/Approach

The vehicle industry, including the three major car manufacturers in the United States and other car manufacturers abroad, is actively searching for better motor drive systems for EV and HEV propulsion systems. The drive characteristics that they desire for EV and HEV propulsion include (1) low cost, (2) high efficiency, (3) safe operation, (4) simple control, and (5) little or no maintenance.

We will develop a low-cost, yet efficient, drive system based on SRM for EV and HEV applications. The design methodology, along with the optimal control scheme, will minimize the motor and converter power rating. So, the total SRM drive cost and drive size will be considerably lower than those of the other potential EV and HEV motor-drive systems that are capable of meeting vehicle performance requirements. A new self-tuning control system will allow low-cost mass production of the drive with higher manufacturing tolerances. Our new position-sensorless, four-quadrant-control scheme will lower the cost of the drive system and will also improve system reliability.

Status

Our group has developed the following elements of this project during past work: drive design methodology for EV/HEV; design methodology for SRM drives; methodologies for four-quadrant, sensorless, self-tuning control of SRM; and theoretical proof that SRM drives produce the best candidates for EVs/HEVs. For this project, we will combine these elements into a laboratory demonstration of an EV/HEV drive with the expected superior performance.

Benefits

Our recent study has revealed that an SRM, if designed and controlled appropriately, is capable of exhibiting the desired torque speed profile for the electrical propulsion systems of a vehicle better than other motors. This capability will substantially reduce the peak power requirement for SRM, compared with other potential traction motors, yet achieve the same vehicle performance. The size of the drive converter will also be reduced. As a result, the SRM could be a low-cost propulsion system for EVs and HEVs.

Topic Area 3

Integrated AC Induction Motor/Inverter/Cooling System for Light-Duty Electric Vehicle Drive Trains

Objective

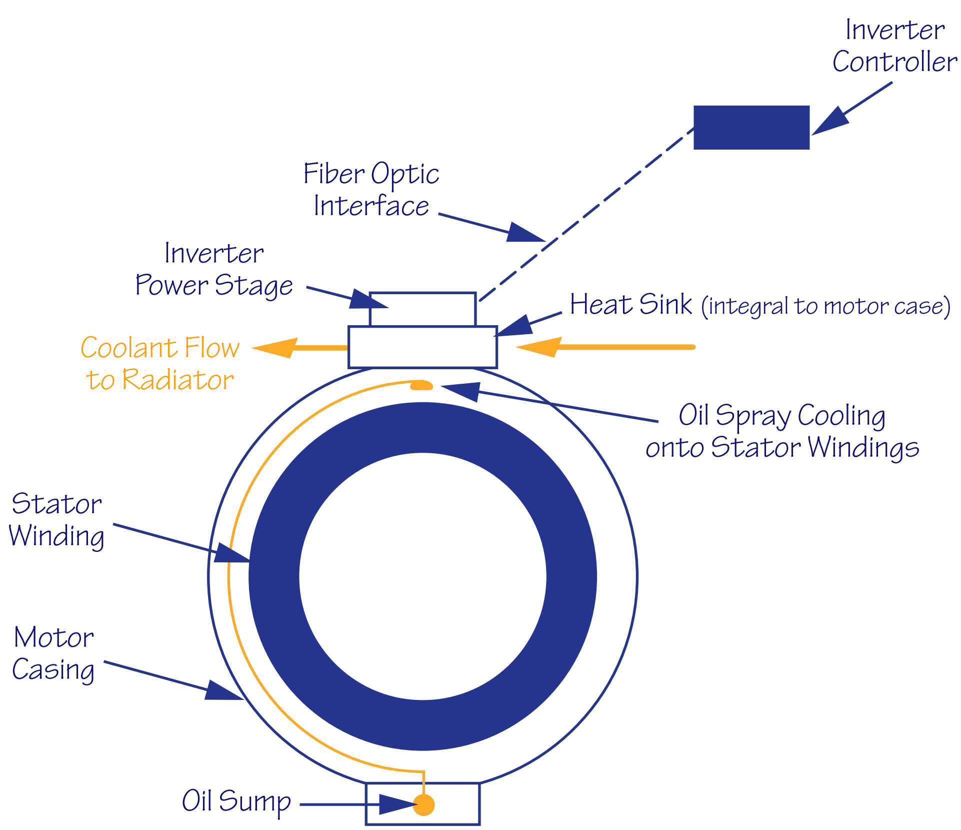
Our objective is to design a high-speed motor for light-duty vehicles that has minimum size and weight. To achieve this objective, we will complete the following tasks: (1) develop a transient thermal model for an integrated motor and inverter power stage, (2) identify a method of mounting the power devices that will improve thermal performance, (3) design a partitioned inverter power stage and controller with fiber optic interfaces, (4) design a sensorless control algorithm for a high-speed AC induction motor, and (5) construct a test-bed hardware system to demonstrate the concept.

Technical Challenge

The key technical challenge is the development of a very-high-speed, high-efficiency AC induction motor, inverter, gearing, and thermal design.

Technical Concept/Approach

Our technical approach is illustrated in the following diagram.



VPT, Inc.
1700 Kraft Dr.
Suite 2350
Blacksburg, VA 24063

Contact
Charles "Bud" Konrad
(540) 362-0947

Status

We have already developed a high-speed (12,000-rpm), 75-hp, 80-frame, 2-pole AC induction motor that is used in a number of electric vehicles and buses. We have also developed an advanced 75-hp , high-efficiency, vector-controlled motor drive. Our 75-hp rotating dynamometer will be employed in the hardware test bed.

Benefits

We expect to achieve a 33% reduction in weight and volume from the existing motor and controller for a system sized to meet the peak power requirements of a light-duty vehicle.

Topic Area 3

Segmented Electromagnetic Array Motor Technology for Electric and Hybrid Electric Vehicles

Objective

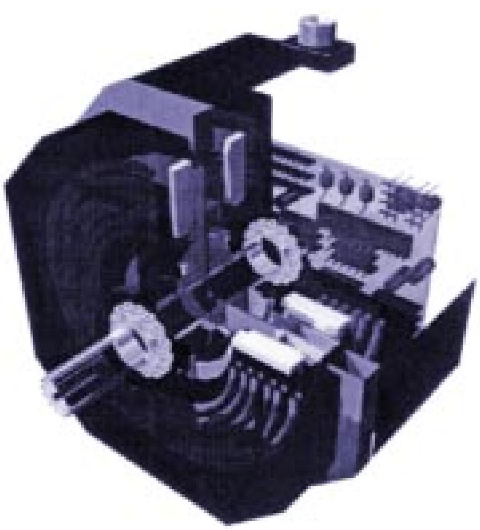
Visual Computing Systems Corp. (VCS) will develop a motor design that is capable of meeting the technical specifications for an EV traction motor. This design will be based on the patented Segmented Electromagnetic Array (SEMA) motor technology. VCS will conduct analyses to select suitable electronic controls and power inverters to be included in an integrated motor module. A detailed simulation of the overall system will be completed to assess the ability of the integrated traction motor to meet performance requirements. VCS will also identify and document suitable processes to manufacture production-level quantities of integrated SEMA motors at low cost. Prototype integrated traction-motor modules will be designed, constructed, and tested during the three-phase CARAT effort.

Technical Challenge

Implementing an electric traction motor in an EV or an HEV requires that the motor be highly efficient and compact. However, the materials and processes required to obtain such high efficiency are currently expensive. Designing a highly efficient electric drive line that is competitive with a conventional internal combustion engine and transmission in terms of cost and performance presents quite a challenge. To make EV/HEV technology pervasive in the automotive market, this critical barrier must be overcome.

Technical Concept/Approach

VCS will work with Lynx Motion Technology Corporation, which is commercializing SEMA technology, and a major automotive company to establish the system-level specifications for the traction motor and electronics.



Conceptual Rendering of the Integrated Motor Module, Illustrating a Potential Implementation of Integrated Power and Control Electronics into the Motor Housing

Visual Computing Systems Corp.
9540 Highway 150
Greenville, IN 47124

Contact
Roy Kessinger
(812) 923-7474

VCS will model several motor design candidates and determine which is best suited for the traction motor application. A detailed analysis will be conducted to determine the design criteria for the electronic controls. IEEE Recommended Practice 1461 will be used as the baseline for the integrated electronic controls and power electronics. The motor and integrated electronics will be modeled to analyze magnetic, electrical, and electromagnetic performance. In future phases of research, prototype motors will be designed and built, and their performance tested in an EV or HEV application.

Status

Technical specifications are being compiled for the detailed design of the motor.

Benefits

Electric motors and motor/alternators based on the SEMA architecture promise devices of unparalleled power density and efficiency and would therefore be ideal for traction motors in EV/HEV applications. This research is expected to yield a high-efficiency SEMA motor that is compatible with the size and cost constraints facing the electric vehicle industry. Introduction of such compact and efficient motors will play a vital role in the production of a practical EV or HEV.

Topic 4

Advanced Water-Gas Shift Catalysts

Fuel cells are being developed to replace internal combustion engines because they are clean, energy efficient, and fuel flexible. The proton-exchange-membrane (PEM) fuel cell, capable of high power density and fast start-up, can run on hydrogen-rich material, such as gasoline, methanol, ethanol, and natural gas. However, the carbon monoxide (CO) that results from reforming the carbon-containing fuels degrades fuel performance; the CO is usually removed by means of a water-gas shift reaction, in which reformed gases are treated with high-temperature steam in the presence of a shift catalyst. The shift catalyst currently comprises about one-third of the mass, volume, and cost of the fuel processing system.

The organizations funded under this topic are working to develop and evaluate improved high- and/or low-temperature shift catalysts that have greater activity than the current catalysts (to allow reduced weight and volume) and increased thermal and environmental stability (to extend catalyst lifetime).

Topic Area 4

Bimetallic Transition Metallic Carbides as New Water-Gas Shift Catalysts

Objective

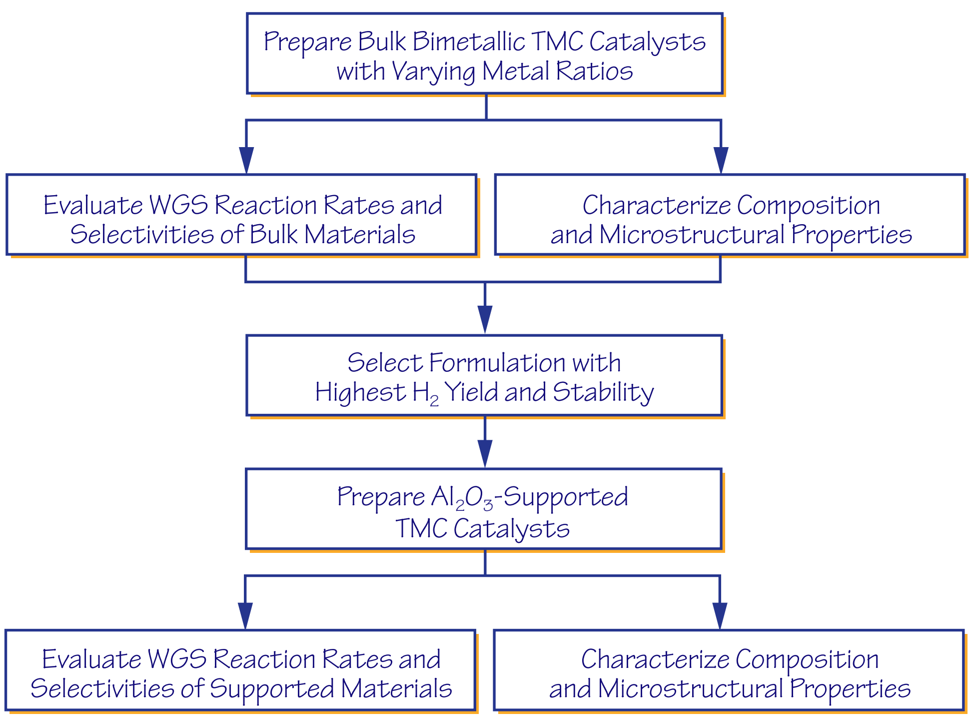
The objective of the Phase I research is to demonstrate the feasibility of using bimetallic transition metallic carbides (TMC) for commercial applications. Catalytic properties of these new materials will be compared to those of present commercial water-gas-shift (WGS) catalysts.

Technical Challenge

The WGS is a critical step during fuel processing, and the associated reactor constitutes about one-third of the mass, volume, and cost of the fuel processor.

Technical Concept/Approach

Fuel cells are being developed by the Partnership for a New Generation of Vehicles (PNGV) to enable the commercialization of cleaner, more fuel-efficient vehicles. The fuel cell technology favored by most vehicle manufacturers is proton exchange membrane (PEM) cells operating with H_2 from hydrocarbon steam reforming or partial oxidation. Rather than seeking incremental improvements through the modification of existing formulations (e.g., iron-chromium and copper-zinc catalysts), we propose to investigate the use of a new catalyst formulation. This new formulation is based on recently discovered bimetallic TMCs. The figure below is a flowchart for the Phase I project.



University of Michigan
Department of Chemical Engineering
3026 H.H. Dow Bldg.
Ann Arbor, MI
48109-2136

Contact
Levi T. Thompson
(734) 936-2015
Fax (734) 763-0459
ltt@umich.edu

During Phase II, compositions and structures of the bimetallic TMC catalysts will be optimized so that their performance significantly exceeds that of presently used WGS catalysts. A key part of Phase II will be application of the TMC catalysts to monolithic (honeycomb) supports. Monolithic supports are preferred because they have proven to withstand vehicular vibrations. During Phase III, we will work with fuel-cell-system and vehicle developers and manufacturers to fully evaluate fuel processors based on our new WGS catalysts. We will formalize the teaming relationships prior to Phase II and, perhaps, during Phase I.

Benefits

The expected result of this project is a substantial reduction in the size, weight, and cost of fuel processors for PEM fuel cells.

Topic Area 4

Nano-Scale Water-Gas Shift Catalysts

Objective

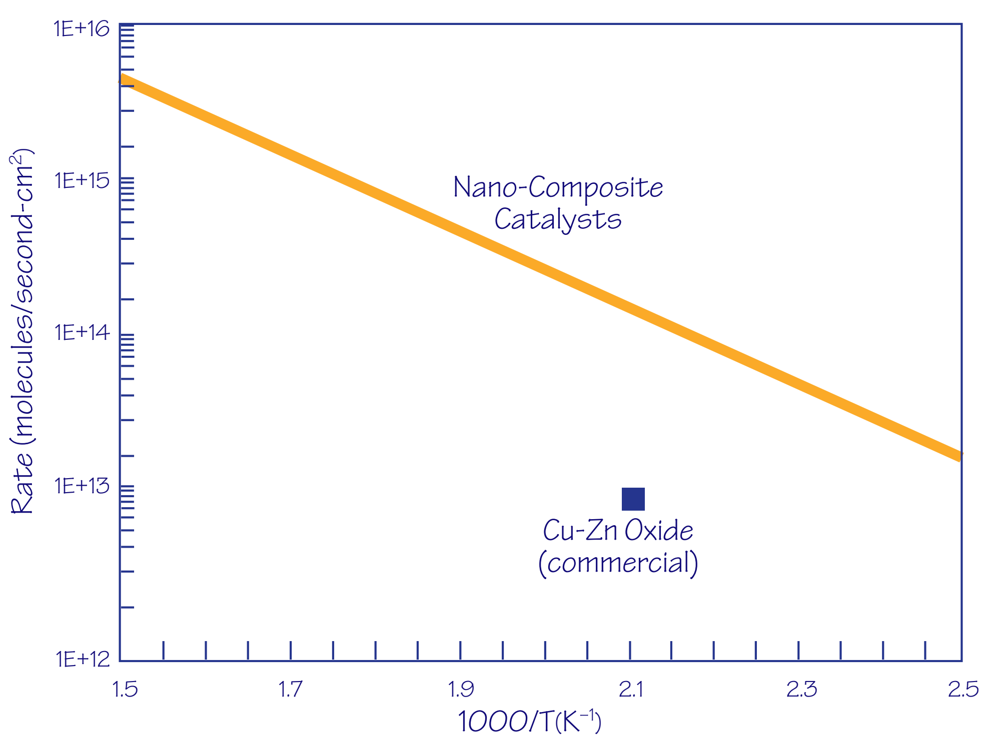
NexTech Materials will collaborate with the University of Pennsylvania, United Catalysts, Inc., International Fuel Cells (IFC), and Epyx, Inc., to develop novel catalysts for on-board fuel processors that convert gasoline into hydrogen-rich gas for automotive PEM fuel cell systems. The overall objective of this program is to increase the performance and durability of water-gas-shift catalysts for both low- and high-temperature reactions.

Technical Challenge

The critical barrier to successful implementation of on-board processing technology is the availability of efficient catalysts that reduce the carbon monoxide concentration in the reformed gas stream.

Technical Concept/Approach

The concept for the program is based on development of nano-scale cerium oxide-based catalysts containing relatively low loadings of precious metals. These types of catalysts have exhibited catalysis rates as much as 100 times faster than those of commercially available catalysts. The figure below compares water-gas-shift rates for nano-scale ceria/platinum, ceria/palladium, and ceria/rhodium nano-composite catalysts with commercial water-gas-shift catalysts.



Comparison of Water-Gas-Shift Rates for Nano-Scale Ceria/Platinum, Ceria/Palladium, and Ceria/Rhodium Nano-Composite Catalysts with Commercial Water-Gas-Shift Catalysts

NexTech Materials, Ltd.
720-I Lakeview Plaza Blvd.
Worthington, OH 43085

Contact
Scott L. Swartz, PhD
(614) 842-6606

Status

NexTech is developing a synthesis process and catalyst composition that will result in improved water-gas shift performance. The developmental catalysts will be evaluated for long-term stability and performance in bench-scale fuel processors at IFC and Epyx.

Benefits

The anticipated benefits of this program are reductions in the volume, weight, and cost of the fuel processor system and an increase in catalyst lifetime. This effort will improve the chances for wide-scale commercialization of fuel cell technology for transportation applications.

Topic 5

Fuel Processing for Fuel-Cell Systems

Fuel cells operate on hydrogen; when fuels other than hydrogen are used—such as natural gas, methanol, ethanol, or gasoline—they must be converted to hydrogen. The current conversion process involves steam reforming, partial oxidation reforming, or a combination of the two. The organizations funded under this topic are working to develop an innovative, efficient, clean, and cost-effective fuel processor to convert natural gas, alcohols, or gasoline to hydrogen that can be used in polymer electrolyte fuel cells for transportation or building applications. The fuel gas generated by the processor is expected to contain less than 100 parts per million carbon monoxide and less than 1 part per million hydrogen sulfide, or it should be easily treated to meet these levels. The processor is expected to function reliably for the life of the vehicle (5,000 hours) or building power source (40,000 hours) and to be produced at high volume and low cost.

Topic Area 5

Compact Single-Stage Fuel Processor for PEM Fuel Cells

Objective

Our objective is to reform liquid hydrocarbons into hydrogen and apply the reforming technology to more complex fuels, like gasoline.

Technical Challenge

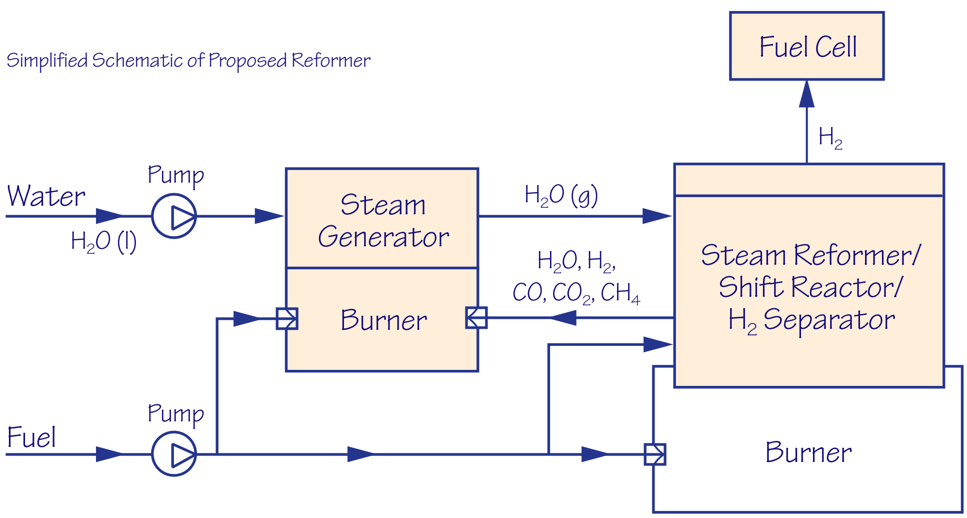
The key challenge is demonstrating the technology's ability to reform complex fuels, like gasoline.

Technical Concept/Approach

The operation of proton-exchange-membrane (PEM) fuel cells depends on the availability of clean hydrogen fuel. The Department of Energy is therefore looking for innovative approaches to convert readily available fuels to hydrogen.

Aspen Systems has developed a simple and efficient method of reforming liquid hydrocarbons into hydrogen. The key to this process is the active removal of the hydrogen from the process (see figure).

Simplified Schematic of Proposed Reformer



The process involves pumping fuel, gasoline, natural gas, or an alcohol into the reactor. Steam is fed into the reactor from a steam generator that is fired by the same type of fuel as the reactor. The fuel is then converted to hydrogen and carbon dioxide with trace amounts of methane and carbon monoxide. The resulting reformer efficiency (ratio of lower heating value of fuel to electric power) is 80%, when the heat consumed by the burners and reasonable losses are included. These results are based on actual tests conducted at Aspen Systems with octane fuel.

Aspen Systems, Inc.
184 Cedar Hill St.
Marlborough, MA 01752

Contact
Hamed Borhanian
(508) 481-5058
ext. 116
hamed@aspensystems.com

Status

Although Aspen Systems has demonstrated this concept on octane in laboratory tests, the next step is to demonstrate it on more complex fuels, such as gasoline.

Benefits

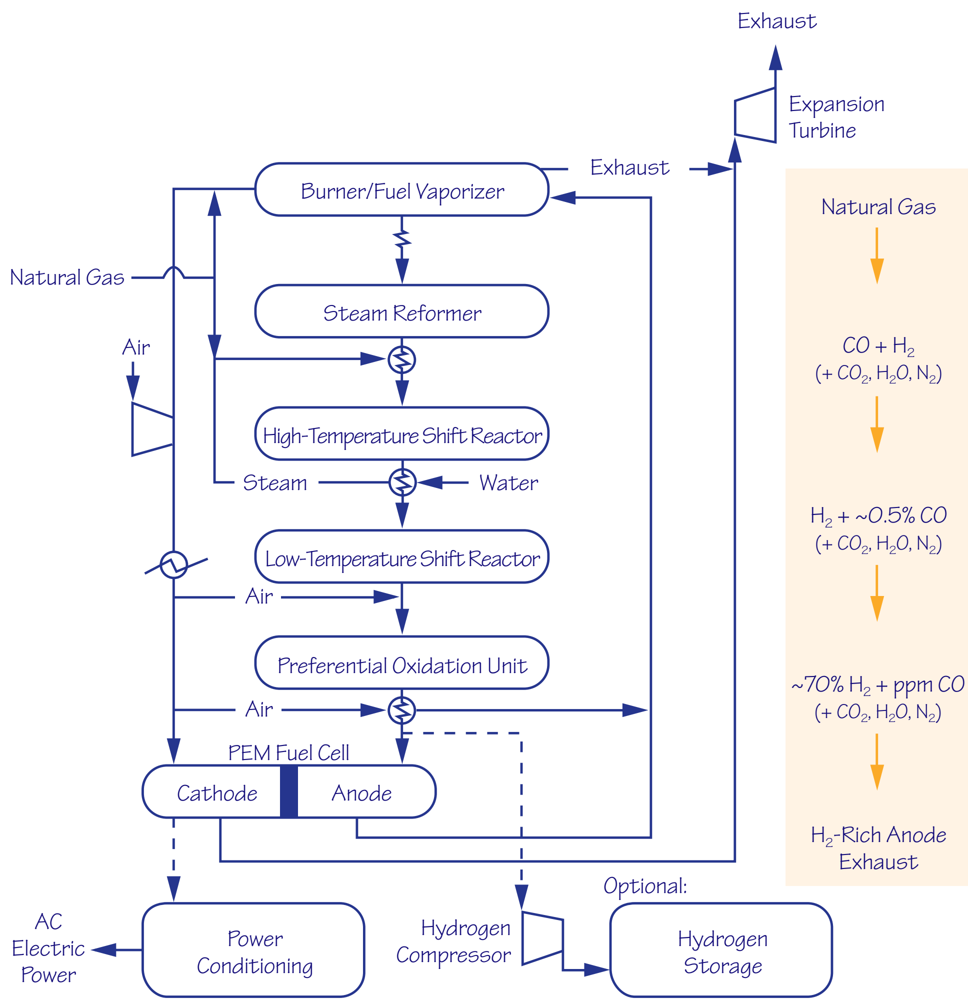
If implemented, the proposed technology will result in coke-free operation (long life), carbon-monoxide-free hydrogen output, and high power densities.

Topic Area 5

Development of an Innovative Natural Gas Fuel Reformer for Electric Power Generation

Objective

The development of power systems based on fuel-processor/proton-exchange-membrane fuel cells (PEMFCs) for automotive applications may significantly influence the parallel development of analogous natural-gas-fueled systems for residential-scale generation of distributed electric power and heat. In Phase I of this project, our objectives are to design an inexpensive, small-scale, PEMFC-based stationary power system that converts natural gas to both electricity and heat and then to analyze the prospective performance and economics of various system configurations (see figure).



Princeton University Center for Energy and Environmental Studies

Princeton, NJ 08544

Contact

Tom Kreutz
(609) 258-5691
Joan Ogden
(609) 258-5470

Technical Challenge

Small-scale PEMFC-based stationary power generation has received only a fraction of the attention given to the transportation market, yet it has the potential to play an important role in the development of future fuel-cell-powered HEVs. The automotive and stationary power plants are quite similar; both require a fuel processor, water-gas shift reactors, a preferential oxidation unit, a CO-tolerant PEMFC stack, and power-conditioning electronics. Thus, progress in the development of mobile PEMFC power plants is likely to speed the development of stationary systems (and vice versa).

Two key considerations suggest that stationary PEMFC power systems could achieve widespread commercial adoption before their automotive counterparts. First, the market entry costs of stationary systems (perhaps $200–400/kW) are much higher than those for mobile power plants ($30–50/kW). Because capital costs are projected to fall rapidly with volume, initial success in the stationary power market could be a critical factor in lowering the barrier to entry in the mobile power market. Second, the technical requirements of a stationary power plant are, with the key exception of system lifetime, significantly less demanding than those for mobile systems, which require the following: short start-up time; good dynamic response; high turndown ratio; high power density; high specific power; and robustness to transient loads, thermal cycling, and mechanical shocks.

Technical Concept/Approach

The specific tasks we will undertake during Phase 1 are as follows:

- Develop computer models for residential-scale PEMFC cogeneration systems, which will allow comparison of various system designs (e.g., steam reforming vs. partial oxidation and compressed vs. atmospheric pressure).
- Determine the most technically and economically attractive system configurations at various scales (e.g., residential, multidwelling, neighborhood) by means of analyzing, in detail, comparative system performance and economics.
- Examine the potential ramifications of widespread adoption of these systems on (1) distributed heat and power generation for residential applications and (2) development and commercialization of both fuel-processor-based and direct-hydrogen fuel-cell-powered EVs.
- Should the analysis in Phase I demonstrate the need for a natural gas reformer at scales much smaller (e.g., in the 4–20 kWh range) than those currently available, develop a proposal for Phase II to design and construct an efficient, low-cost version to serve as a foundation for such a residential power system.

Benefits

As a result of this research, we expect to gain a better understanding of residential-scale PEMFC cogeneration systems and the role that their widespread adoption might play in the codevelopment of PEMFC-powered HEVs.

Topic Area 5

A Novel Fuel-Processing System for PEM Fuel Cells

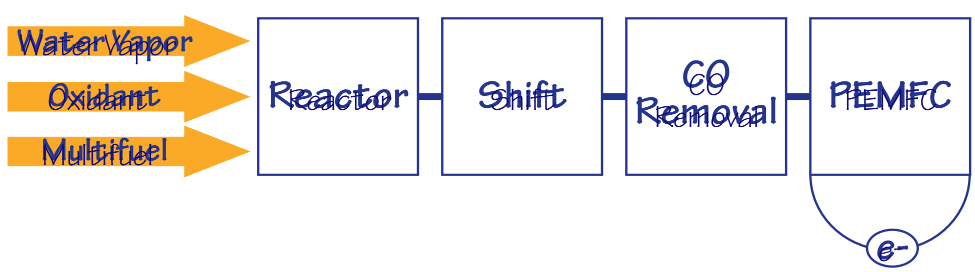
Objective

Our Phase I objective is to demonstrate the feasibility of integrating a unique, multifuel processing system with a PEM fuel cell (PEMFC). The novel integrated system should increase overall system efficiency by 6% compared with that of conventional approaches to both fuel processing and PEMFC operation for vehicle traction and other applications.

Technical Challenge

Efficient PEMFCs can only operate on hydrogen fuel. When installed in alternative-fuel vehicles, they will reduce energy use per mile by 60% compared with that of conventional vehicles of similar curb weight powered by gasoline. In addition, the hydrogen may be produced from domestic natural gas, thereby reducing the carbon dioxide emissions associated with the conventional fuel transportation infrastructure by three orders of magnitude. The production of pure carbon dioxide on-site could permanently sequester this greenhouse gas. Finally, this new fuel infrastructure could reduce or eliminate oil imports.

However, a hydrogen infrastructure does not exist, and means must be found to use the $200 billion oil-products infrastructure. The feasibility of employing gasoline partial oxidation with water-gas shift to complete hydrogen production, followed by carbon monoxide cleanup, has been demonstrated. However, aboard a vehicle, even if they work well, such systems will be much less efficient than pure hydrogen approaches. To make the multifuel PEMFC electrochemical engine competitive with internal combustion hybrids, improved system efficiencies are required.



Technical Concept/Approach

Researchers have identified means to increase the overall system efficiency by 6% to better than 35–40% overall if certain operational parameters in the fuel processor and PEMFC can be achieved. This improved efficiency will be subject to experimental verification in Phase I.

Status

Engineering calculations have been performed, and certain operating parameters have been identified in previous and other ongoing work.

Texas A&M University

Texas Engineering Experiment Station

Center for Electrochemical Systems and Hydrogen Research (CESHR)

238 WERC
College Station, TX
77843-3402

Contact

A. John Appleby
(409) 845-8281
Fax (409) 845-9287
ajappleby@tamu.edu

Benefits

Multifueled vehicles powered by electrochemical engines will be far more efficient and practical than conventional vehicles.

Topic 6

Advanced Membranes and Membrane-Electrode Assemblies

Significant research is necessary to improve the performance and reduce the costs of membranes and membrane-electrode assemblies for fuel cells. Current challenges include overcoming water management problems, preventing CO poisoning of the anode catalyst (in PEM fuel cells), and eliminating methane diffusion (in direct-methanol fuel cells [DMFCs]). The organizations funded under this topic are working to develop improved or alternative low-cost polymer membrane systems that will (1) perform reliably at temperatures 80–90°C higher than temperatures at which current membranes can function, (2) enable fuel cells to operate at 120–200°C to eliminate CO poisoning and minimize water management problems, and (3) allow little or no methanol diffusion in DMFCs. The research will also provide low-cost methods for fabricating membrane-electrode assemblies at high volumes.

Topic Area 6

High-Temperature, Direct-Methanol PEM Fuel Cells

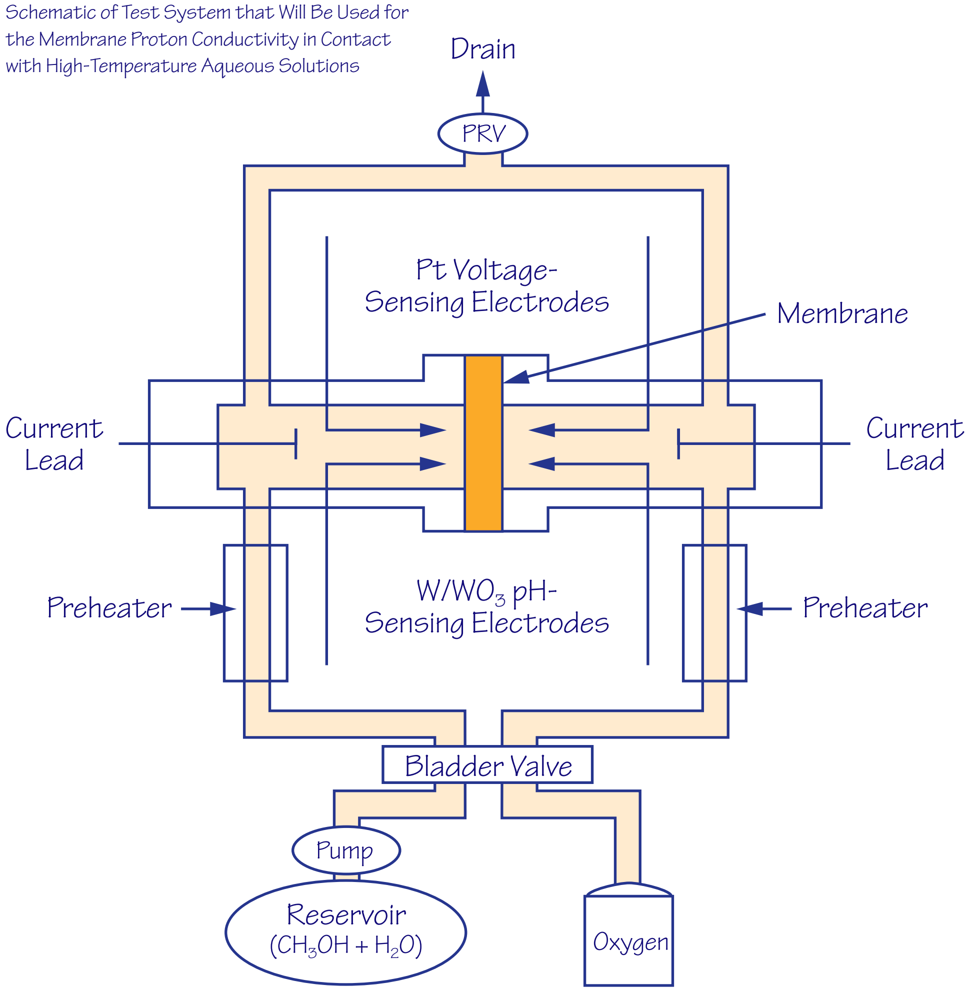
Objective

The purpose of this project is to synthesize and evaluate a new class of ion-exchange membranes for PEM fuel cells.

Technical Challenge

Current membranes, such as Nafion, have operating temperature limits of about 80°C. At higher temperatures, the membranes dehydrate, resulting in a substantial increase in resistivity and a loss of mechanical stability. The principal challenges in this project involve the design and synthesis of polymer membranes that are thermally and electrochemically stable at elevated temperatures and the minimization of fuel (e.g., methanol) carryover.

Schematic of Test System that Will Be Used for the Membrane Proton Conductivity in Contact with High-Temperature Aqueous Solutions



Pennsylvania State University Center for Advanced Materials

517 Deike Building
University Park, PA
16802-2714

Contact

Harry Allcock, PhD
(814) 865-3527
Serguei Lvov
(814) 863-8377

Technical Concept/Approach

We will explore various polymers that are based on the polyphosphazene system, particularly those that contain sulfonate, carboxylate, phosphate, and phosphonate anions; these constituents will allow fuel cells to operate at elevated temperatures, perhaps as high as 250 °C. These polymers will be used because of the thermo-oxidative and reductive stability of the phosphorus-nitrogen backbone, and because of their ability to permit large or subtle changes to be made in side-group structure to optimize membrane properties. We will employ unique experimental techniques to characterize the proton and fuel transport characteristics of the membranes, including methods for measuring proton activity at the membrane surface at elevated temperatures. We will also use novel frequency-domain techniques to explore the dynamic transport properties of the system at temperatures of up to 250 °C.

Benefits

The benefits expected by exploring the higher-temperature (100–200 °C) fuel cell include the following: (1) faster reaction rates may decrease, or even eliminate, the need for noble metal catalysts and may yield greater tolerance to CO poisoning at the anode; (2) the higher proton mobilities will decrease the membrane resistivity; and (3) the higher temperatures will enhance the prospects for developing direct-fueled fuel cells (i.e., cells that do not require the reforming of the fuel to hydrogen).

CARAT

Topic Area 6

Novel Membranes for PEM Fuel Cell Operation at 150-200 °C

Objective

The objectives of the work are to synthesize and evaluate two novel classes of membranes — heteropolyacid/polymers and fast proton-conducting glasses — as electrolytes for PEM fuel cells (PEMFCs) capable of operating at 150–200 °C.

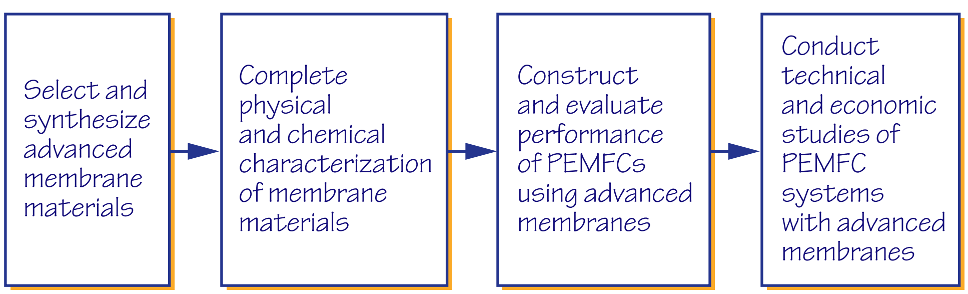
Technical Challenge

PEMFCs operating at 150–200 °C will overcome significant technical problems, including minimizing the problem of CO poisoning (adsorption of CO onto the platinum catalyst is greatly reduced at these temperatures), potentially yielding better solutions to the water and thermal management problems that are encountered in the state-of-the-art PEMFCs, and potentially yielding PEM materials that are less expensive than those currently used.

Technical Concept/Approach

The work involves the following tasks:

- Preparing novel membrane materials.
- Evaluating the physicochemical and morphological characteristics of these membranes.
- Constructing and performing evaluations of PEMFCs by using these membranes.
- Conducting technical and economic assessments of PEMFC systems, using the novel membranes as electrolytes, for EV and other applications.



Princeton University Center for Energy and Environmental Studies

Princeton, NJ 08544

Contact

Joan M. Ogden
(609) 258-5470
Supramaniam Srinivasan
(609) 258-5217
Andrew Bocarsly
(609) 258-3888

Status

The project began October 1, 1998. A fuel cell test station has been installed, and we are evaluating alternative methods for membrane preparation.

Benefits

If the novel membrane materials are found to perform well at 150–200 °C, the problem of carbon monoxide poisoning of the platinum catalyst would be overcome, as would the thermal and water management issues for fuel-cell systems. In addition, these materials have the potential to be less expensive than current membrane materials.

Topic Area 6

Advanced Direct-Methanol Fuel Cells

Objective

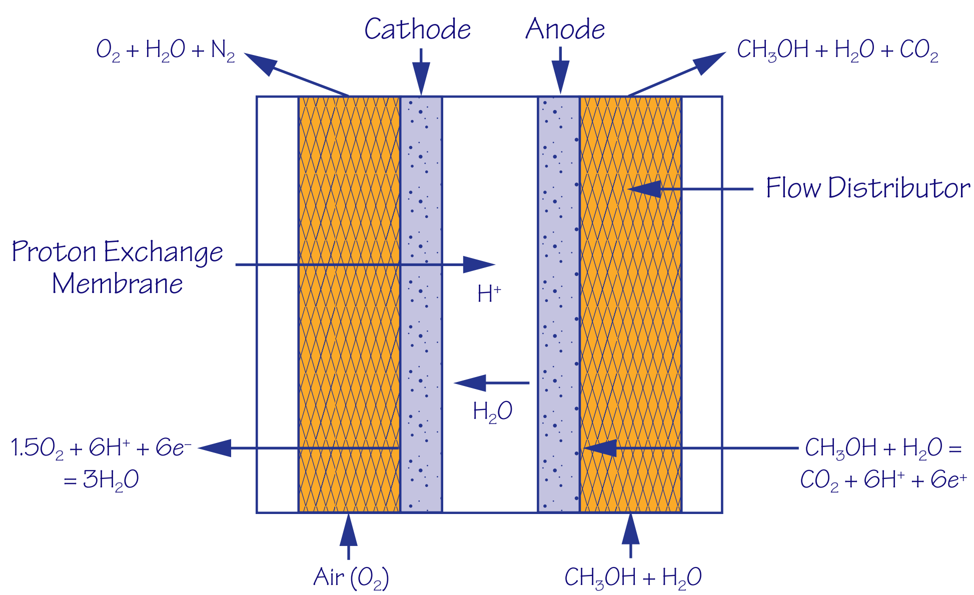
The objective of this project is to develop an advanced membrane for use in a DMFC that reduces methanol crossover by more than 90% compared with current membranes.

The project will involve the following key tasks:

- Demonstrate the feasibility of fabricating a low-resistance, high-methanol-exclusion membrane;
- Identify and evaluate important physical/chemical properties of the advanced membrane;
- Demonstrate membrane performance in single-cell and multicell DMFC stacks; and
- Conduct a cost analysis, projecting membrane and membrane-electrode assembly manufacturing costs.

Technical Challenge

The challenge is to decrease methanol crossover and still provide high fuel-cell performance.



Technical Concept/Approach

Proprietary processes will be used to fabricate membranes with increased resistance to oxidation and decreased methanol permeability. These processes will also reduce the membrane preparation time, resulting in lower-cost membranes. The membranes will be used as shown in the figure.

Status

Preliminary advanced membranes have been prepared and are undergoing initial evaluation.

Giner, Inc.
14 Spring St.
Waltham, MA
02154-4497

Contact
John A. Kosek, PhD
(781) 899-7270
Fax (781) 894-2762

Benefits

Development of an advanced membrane with reduced methanol crossover would significantly improve both the efficiency and the performance of DMFCs in transportation applications.

Topic 7

Low-Cost Carbon Monoxide and Hydrogen Gas Sensors

Chemical species like carbon monoxide and hydrogen must be monitored within the fuel cell system to ensure its safe, reliable operation. The organization funded under this topic is working to develop low-cost sensors to detect carbon monoxide and hydrogen in a PEM fuel-cell environment. The sensors should be able to detect the presence of (1) carbon monoxide at concentrations as low as 10 ppm in the gas mixture entering the fuel stack and (2) hydrogen at concentrations as low as 4% in the fuel-cell compartment of a vehicle. In addition, the sensors should function adequately in an automotive environment, perform reliably, enable low-cost production, and respond rapidly to changing conditions.

Topic Area 7

Low-Cost Carbon Monoxide and Hydrogen Sensors

Objective

Our objective is to produce several advanced-design amperometric gas sensors that overcome the current limitations of chemical sensors and to test their feasibility for use in automotive applications.

Technical Challenge

The requirements for sensors in automotive applications include a combination of high performance, long lifetime, and low cost. The current design of small carbon monoxide and hydrogen sensors does not allow them to meet these requirements.

One key to designing the new sensor will be our ability to form a mechanically strong and electrically conductive bond from the sensor electrode to the conductive plastic housing (as shown in the figure) so that the electrochemical reaction can be detected through the sensor housing.

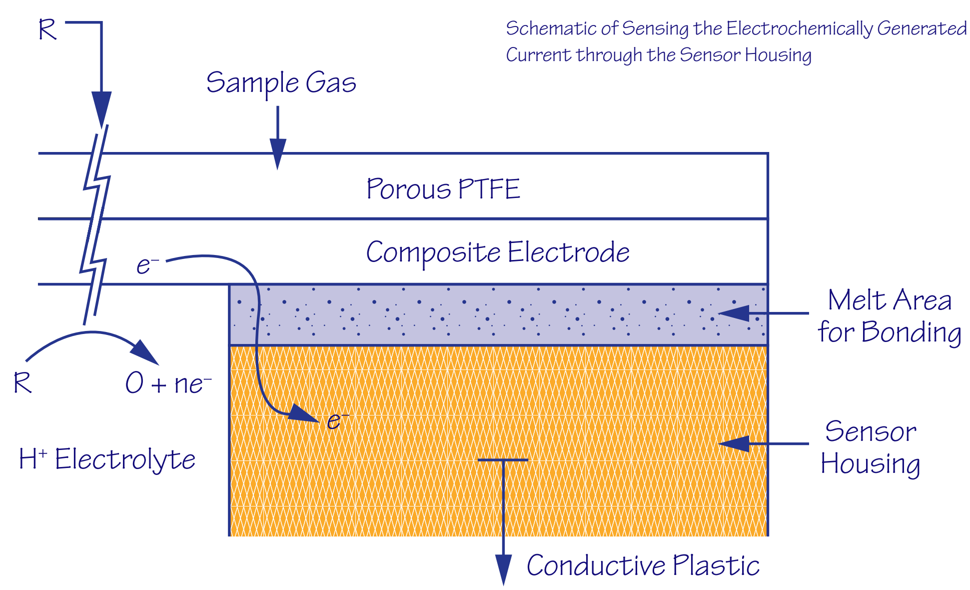
Technical Concept/Approach

We will use a combination of unique low-cost design methods and a modern electroanalytical approach incorporating advanced catalyst formulations and new materials to provide one or more designs for gas sensors that can meet stringent automotive requirements.

Status

IIT has begun exploring ways to form the required bond from the sensor electrode to the conductive plastic housing to allow detection of the electrochemical reaction.

Schematic of Sensing the Electrochemically Generated Current through the Sensor Housing



Illinois Institute of Technology Center for Electrochemical Science and Technology

3300 S. Federal St.
Chicago, IL 60616

Contact

Joseph R. Stetter PhD
(312) 567-3443
Fax (312) 567-3494

Benefits

The project will result in a sensor that can be used effectively in fuel-cell-powered and other types of alternative-fuel vehicles. The new manufacturing methods developed will allow lower-cost sensor design in other markets served by the amperometric gas sensor (e.g., industrial hygiene and safety, environmental, and medical applications). The methods developed for sensing CO and H_2 will allow greater lifetime and stability for the amperometric sensor; the methods can also be applied to improve the performance of NO_x, SO_x, O_2, and other gas sensors and allow these sensors to be used in applications that are not now possible.

Topic 8

Computer Models for Simulation of Fuel-Cell Performance

Fuel-cell models are needed to understand how various critical parameters, like heat transfer, droplet formation, and electrochemical reactions, affect fuel-cell design. Processes and conditions in the vicinity of the reaction sites are of particular interest. Organizations funded under this topic are working to develop comprehensive computer models for realistic and accurate simulation of fuel-cell performance. The goal is to develop three-dimensional models that are based on new codes or subroutines or on existing computational packages, such as FLUENT, FIDAP, TRANSYS, and FIRE, that involve realistic fuel-cell size and velocities. Models must be capable of handling both steady-state and transient operation. Researchers should be able to use steady-state models to investigate the effects of operating conditions, cell materials, and cell geometry and transient models to investigate the effects of any perturbation on fuel-cell performance.

Topic Area 8

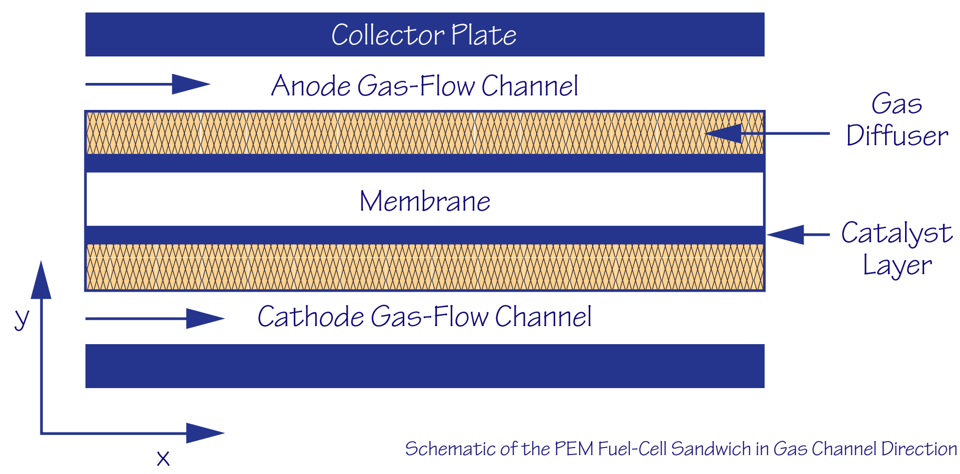
Comprehensive Computer Models for Simulating Fuel-Cell Performance

Objective

The objectives of Phase I of the project are to identify the important phenomena and parameters in fuel-cell operation, to study their interrelationship, and to develop computer models capable of solving all the governing equations in a unified domain simultaneously. The model's inputs will be the same as those in real-life fuel-cell operations, thus eliminating errors caused by arbitrary or simplified interfacial boundary conditions.

Technical Challenge

Fuel-cell operation involves many chemical and physical processes, such as multispecies and multiphase fluid flow, heat and mass transfer in porous media, electrochemical reactions and heat generation in the catalyst layer, and proton and water transfer in the membrane. These processes occur in different regions of a fuel-cell sandwich (shown in the figure), which is made up of two gas-flow channels, two gas diffusers, two catalyst layers, and a membrane. The technical challenge is to solve the governing equations for the many processes in various regions that have different properties and length scales without imposing arbitrary interfacial boundary conditions.



Schematic of the PEM Fuel-Cell Sandwich in Gas Channel Direction

Technical Concept/Approach

To eliminate the errors introduced by prescribing approximate boundary conditions at the various interfaces between the different regions of the fuel-cell sandwich, the governing equations for all the processes will be solved in a unified domain consisting of all the different regions. We will develop a general mathematical model for all the regions, with each region representing a special case of the general model. By using this approach, we will solve the same set of equations in a unified domain with different properties—eliminating the need to impose arbitrary boundary conditions at the various interfaces.

University of Miami
Department of Mechanical Engineering
P.O. Box 248294
Coral Gables, FL 33124

Contact
Hongtan Liu, PhD
(305) 284-2019
hliu@miami.edu

Status

A preliminary two-dimensional unified model has been successfully developed, and very good results have been obtained. Modeling results have been published in several papers, including an article scheduled to be published in the AIChE Journal.

Benefits

The success of this proposed project will result in a comprehensive computer model for real-life PEM fuel-cell performance. Such a computer model will be very useful for fuel-cell system design, research, and development. Such advances in fuel-cell modeling, together with advances in other critical areas of PEM fuel-cell technology, will enhance the commercialization of fuel-cell energy systems.

Topic Area 8

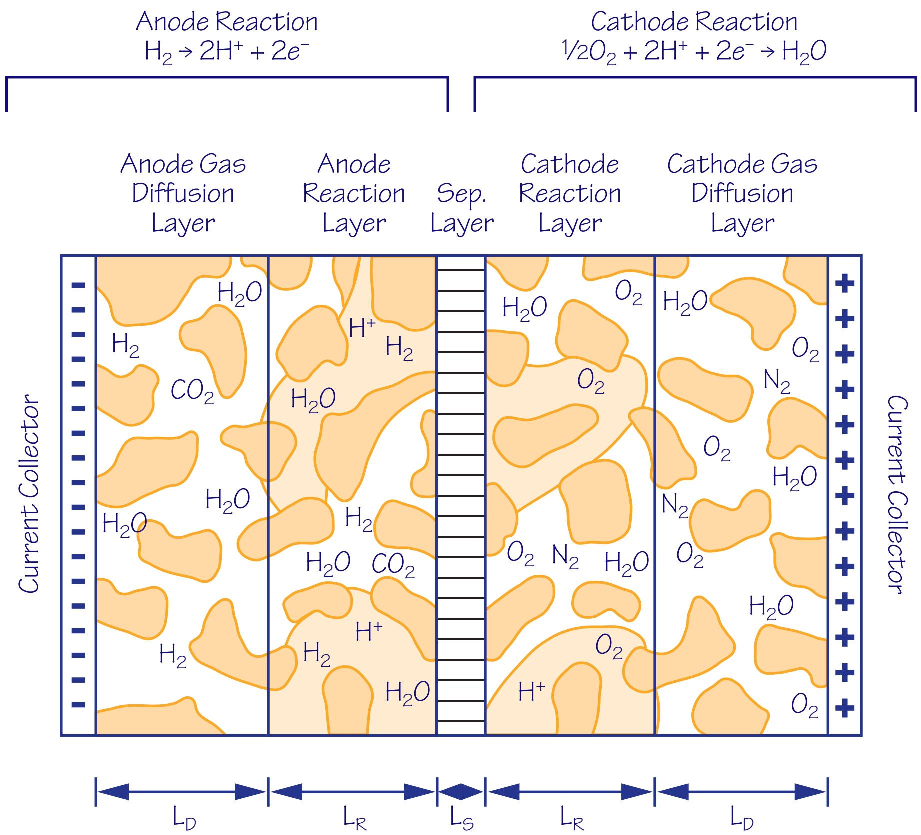
Mathematical Modeling of PEM Fuel-Cell Stacks

Objective

Physical Sciences, Inc. (PSI) will develop a mathematical model of a PEM fuel cell. The work conducted during Phase I will result in a model of a single cell that describes the thermal distribution and the fluid flow phenomena that occur in the bipolar plates, anode and cathode electrodes, and separator. The model will be extended to a fuel-cell stack during the Phase II program.

Technical Challenge

The development and verification of a single-cell model is required before a complete fuel-cell stack can be adequately simulated. Stack development is often complicated because of the intricacies introduced by each cell, as well as by such stack features as manifolds and headers. As fuel-cell developers direct their efforts toward engineering low-cost, high-performance stacks, a better tool will be required to understand the physical and chemical phenomena occurring in the stack.



Schematic of Membrane and Electrode Assembly for the Fuel Cell Model

Physical Sciences, Inc.
20 New England
Business Center
Andover, MA
01810-1077

Contact
Michael C. Kimble, PhD
(978) 689-0003
Fax (978) 689-3232

Technical Concept/Approach

PSI will use the single-cell model to predict the thermal and fluid-flow distributions within the flow-field/bipolar plate assemblies; the assemblies will be coupled with a one-dimensional model of a membrane and electrode assembly (shown schematically in the figure).
Inlet conditions to the single cell will be defined by the conditions within the stack manifolds—including the gas pressure, flow rate, temperature, concentration, and water content in the gas. PSI will use the performance predictions from the single cell to calculate the pressure drops across the cell, the heat transfer into the adjoining cells or cooling/heating plates, and the distribution of the local current density. The pressure drops and thermal loads will then be used in a manifold model (Phase II effort) to simulate fuel-cell stacks. PSI will verify the model by using a specially instrumented single-cell test fixture to collect fuel-cell data, which will make it possible to compare the data with predictions based on the model.

Status

PSI has developed thermal and fluid transport models for the PEM fuel-cell bipolar plates. We will extend this work to complex flow patterns in the bipolar plate, coupled with transport into and out of the neighboring membrane and electrode assemblies.

Benefits

The mathematical modeling approach described here offers fuel-cell developers a better tool for designing and understanding the performance of PEM fuel-cell stacks. At the core of the stack model is a single-cell model featuring heat and fluid flow in the bipolar plates, coupled with a simplified membrane and electrode model. Prediction of these phenomena is essential to developing a simulation tool that accurately describes a complete PEM fuel-cell stack. The modeling approach will save time and money by reducing the number of costly experiments and the development of costly hardware.

Topic 9

Simple Particulate Emissions Measuring System

Current methods for measuring particulate matter emissions in diesel and other internal combustion engines require expensive, complex equipment and are difficult to use. Organizations funded under this topic are working to develop a simple, accurate, and user-friendly sensor to directly or indirectly measure particulate matter emissions from internal combustion engines. The goal is to develop a measuring system that is just as accurate but significantly simpler, less expensive, and easier to use than current dilution-tunnel, filtration-based systems. The improved system should be able to measure the most common types of particulates (carbon particles, liquid droplets, sulfate particles) as small as 1 micrometer. A system capable of making continuous (transient) measurements (with updates every 5 seconds, minimum) would be particularly attractive to industry.

CARAT

Topic Area 9

Novel, Low-Cost, Real-Time Particulate Monitor

Objective

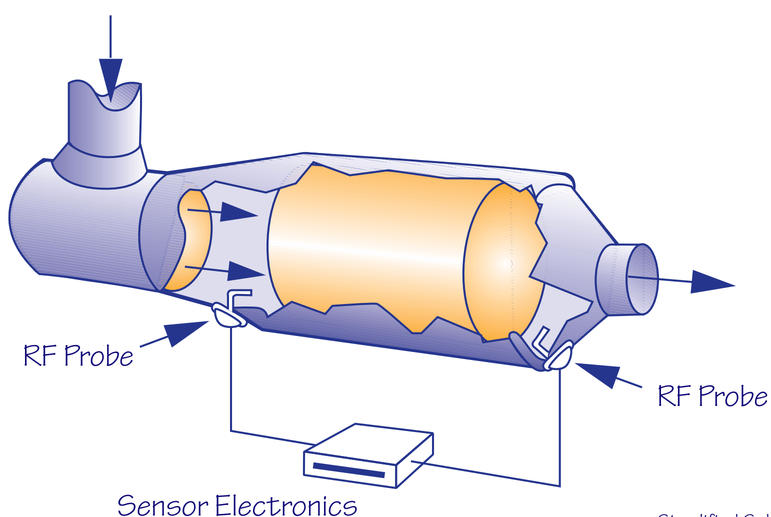
Our objective is to fabricate and test a prototype, real-time instrument to measure particulate matter emissions in internal combustion engine exhaust. We have targeted three performance qualities: (1) measurement of all particulate matter, including sub-micrometer particulates, with sensitivity and accuracy comparable with that of the existing dilution-tunnel/filtration/gravimetric technique; (2) capability of differential measurements, with a cycle time as short as 5 seconds; and (3) low cost, compared with full-flow dilution-tunnel systems, and potentially suitable for local vehicle emissions inspection stations.

Technical Challenge

The proposed monitor will use RF energy absorption to determine soot loading in a miniature diesel particulate filter (DPF). The critical barrier is the fabrication of a small DPF sensor that has the sensitivity, accuracy, and reproducibility required for a practical particulate monitor.

Technical Concept/Approach

The instrument will use a backpulse-regenerable, ceramic-membrane-coated filter previously developed by CeraMem for quantitatively complete removal of particulates from diesel exhaust. We will measure cumulative particulate collection on the filter during a test cycle by using a highly sensitive, RF-energy-absorption technique previously developed by AECL (Atomic Energy of Canada Ltd.) to determine soot loading in diesel exhaust soot filters. Differential readings of RF signal attenuation over a timed collection interval will be correlated with differential mass collection during the particulate collection interval. An integral reading at the end of an engine test will give the total particulate emissions level over the test. By ramping up the temperature at the end of sampling, we will be able to differentiate between condensable and non-condensable particulate fractions.



Simplified Schematic of Particulate Filter with RF Sensor

CeraMem Corporation
12 Clematis Avenue
Waltham, MA 02154

Contact
Robert L. Goldsmith
(781) 899-4495
ext. 24

Benefits

Successful completion of the project will provide a real-time instrument for measuring particulates from engine exhaust.

CARAT

Topic Area 9

Low-Cost System for Measuring Diesel Engine Emissions

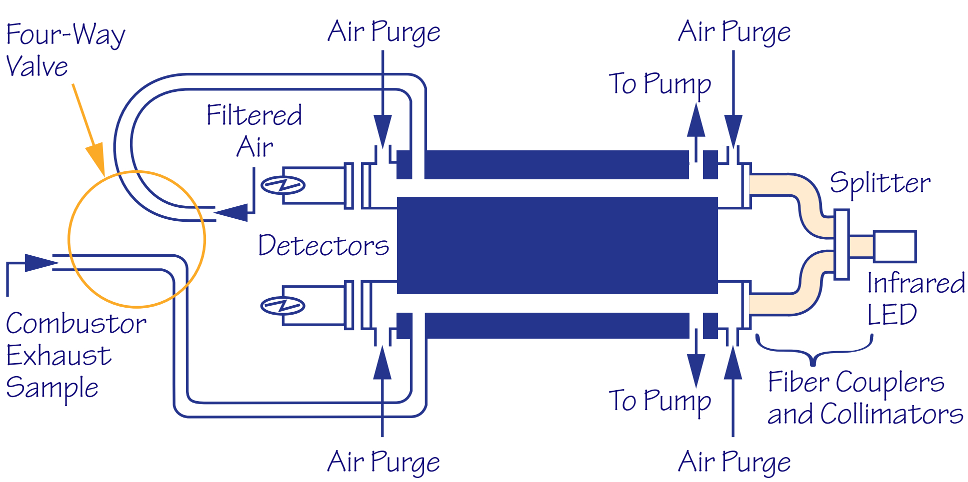
Objective

To design and certify new engines with lower particulate matter emissions, researchers must be able to measure very low levels of particulate matter. Current U.S. EPA testing protocol involves dilution of the exhaust and extraction of a filter sample. The time required to collect a gravimetric sample and the complicated procedure required to determine the weight of the sample make it impossible to use this method to study transient engine behavior. Real-time methods for particulate measurement have been tested but have not always provided a 1:1 correspondence with EPA's filter protocol.

Physical Sciences, Inc., will demonstrate an optical measurement method that will provide real-time data on engine exhaust particulate matter. The data generated as a result of using this method will be comparable with those obtained by means of standard gravimetric methods.

Technical Challenge

The major technical challenge in this project will be to demonstrate the proven ozone detection scheme for diesel particulate matter at concentrations and environmental conditions that correspond to those encountered in a dilution tunnel.



Technical Concept/Approach

The proposed approach is based on a proven concept for measuring absorbance of light at very low absorption levels; this approach has been applied to the measurement of ozone in the upper atmosphere. PSI's photometer concept has been implemented in the form of a robust and reliable instrument capable of unattended operation. PSI will reconfigure the ozone photometer to measure diesel particulate matter under dilution-tunnel conditions.

Physical Sciences, Inc.

20 New England Business Center
Andover, MA 01810-1077

Contact

W. Terry Rawlins, PhD
(978) 689-0003
Fax (978) 689-3232

Status

The PSI ozone photometer, on which the diesel particulate monitor will be based, has reached the beta prototype stage. The basic photometer signal-processing circuit has been designed and implemented in several research-grade instruments.

Benefits

The proposed instrument will allow engine developers to obtain real-time data on particulate emissions that are comparable with data collected by using the EPA test protocol. This capability will advance the development and testing of ultra-low-emission diesel engines.

Topic 10

Variable-Valve Timing Device for High-Speed CIDI Engine

Variable-valve timing devices are becoming more popular in reciprocating internal combustion engines. However, many of the devices now in use can be complex, bulky, and relatively expensive, so their applications tend to be limited. Organizations funded under this topic are working to develop a novel or improved variable-valve timing device that is low in cost (<$3/kW in volume) and that allows continuous (or nearly so) intake and/or exhaust valve timing shift over a wide range during normal engine operation. The device should be suitable for operation in a small-displacement (1–2 L), high-speed (4,500 rpm), compression-ignition engine. The device should also be relatively simple and lightweight, and package well with a number of popular valve-train configurations.

Topic Area 10

Variable-Valve Timing System for Camless Engine Operations

Objective

An electrohydraulic camless valve train was first conceived of by Ford Motor Company. This device, as shown in the figure, is compact and relatively simple. The goal of this research effort is to investigate the feasibility, address the technical challenges, and develop the enabling control capability of such a device for camless operation of small, compression-ignition, direct-injection (CIDI) engines.

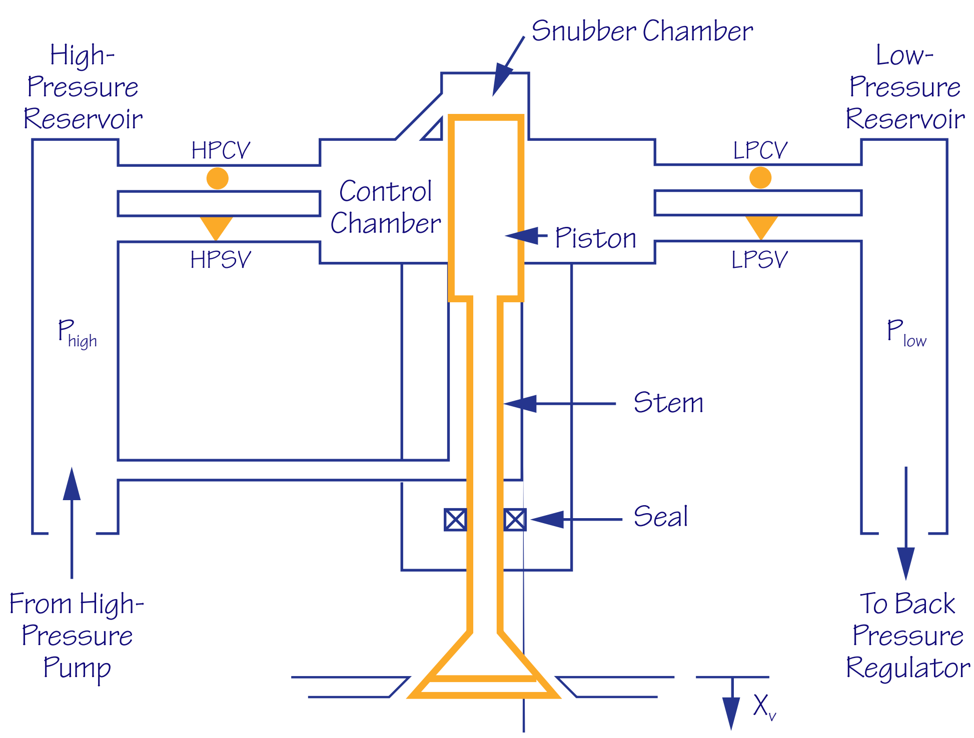
Technical Challenge

Electrohydraulic camless valve trains can be complex, bulky, and relatively expensive, so their applications tend to be limited.

Technical Concept/Approach

Researchers from the University of Illinois at Urbana-Champaign and the University of California at Santa Barbara will conduct systems-oriented research to complete the following tasks:

- Develop a system dynamics (electromechanical-hydraulic) model and simulation for the proposed actuating system.



Schematic Diagram of a Single-Valve Actuating Device

University of Illinois at Urbana-Champaign

Department of Mechanical and Industrial Engineering

Urbana, IL 61801

Contact

T.-C. Tsao

(217) 333-2905

- Develop electronic control methods for valve timing, lift, soft seating, and multiple valve operations.
- Integrate an instrumented variable-valve timing system on an engine head with electronic drivers and control interface software. The 16-valve system will be fully electronically driven via triggering from the crank angle of an engine running in parallel.
- Characterize the system performance envelope, energy consumption, and sensitivity to environmental conditions through both simulation and experiment.
- Use the proposed actuating system to develop a system- and control-oriented dynamic model of CIDI engines and investigate the feasibility of the control configurations and strategies.

Status

The dynamics and lift control of single paired-valve motion have already been investigated. Our project will focus on dynamics and operations of a full 16-valve system.

Benefits

Most existing variable-timing systems, which perform a camshaft phase shift or a switch to another cam lobe profile, offer measurable improvements at some engine operating points. A microprocessor-controlled camless valve train, which continuously adjusts the parameters of valve motion with changing operating conditions, offers much more flexibility and potential benefits because it allows more complete optimization of engine events over the entire operating speed range.

Topic 16

Development of Novel Battery Systems

Although great strides have been made in advanced battery development for EVs and HEVs, no currently available system fulfills all of the performance, life, and economic characteristics required for optimal EV and HEV performance. Organizations funded under this topic are working to develop improved or alternative concepts for advanced batteries that meet the long-term requirements of the U.S. Advanced Battery Consortium (USABC) for EV batteries or those of the PNGV for high-power energy storage. Innovations are expected to be developed in small full or half cells and should be evaluated according to the test procedures published by USABC.

Topic Area 16

Improved, Low-Cost Lithium Polymer Battery System for Electric and Hybrid Electric Vehicle Applications

Objective

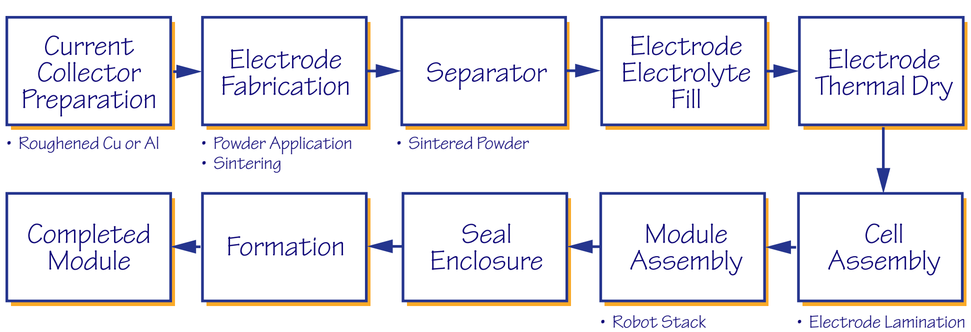
The purpose of this project is to develop an improved, low-cost lithium polymer battery system for EVs and HEVs. The expected improvements in performance and cost will be obtained principally through a novel manufacturing process referred to as the Continuous Polymer Sintering (CPS) process. The objective in Phase 1 will be to physically demonstrate the technical and economic viability of adhering continuously porous, well-structured polymer electrodes to the appropriate active material by using the CPS process.

Technical Challenge

There are fundamental limitations to the performance of a lithium battery produced by means of an extrusion manufacturing process. The extrusion process involves mixing active materials with polymer powders and solvents and extruding the electrode materials onto a current collector. The thickness of the electrode determines the ratio of active to inert materials, which in turn determines the specific energy and power of the battery. In practice, the characteristics attainable by means of a rolling process are limited by the rheology of the electrode material mixture. In addition, because the rolling process fails to provide sufficient material contact between the electrode active mass and the current collector, high pressure is required for the test cell to function. The manufacturing process is also extremely slow and complicated.

Technical Concept/Approach

The manufacturing process proposed is based on the direct and continuous sintering of polymer-based electrode mixtures to the battery current collectors. The CPS process should be able to accommodate a wide spectrum of active material. The figure depicts the different steps involved in the process. The electrochemical viability of this process will be verified through laboratory testing of samples. We will use commercially available active materials that have demonstrated the best performance in lithium batteries to date.



CPS Lithium Polymer Fabrication Process

Electrosource, Inc.
2809 IH 35 South
San Marcos, TX 78666

Contact
Eddie Forouzan, PhD
(512) 753-6519
Benny Jay
(512) 753-6525

Status

Theoretical calculations have been performed, and a series of suitable active materials has been selected for proof-of-concept work.

Benefits

The proposed sintering process is geared toward significantly increasing the production rate of lithium polymer battery electrodes. These electrodes will be easier, and ultimately cheaper, to produce.

CARAT

Topic Area 16

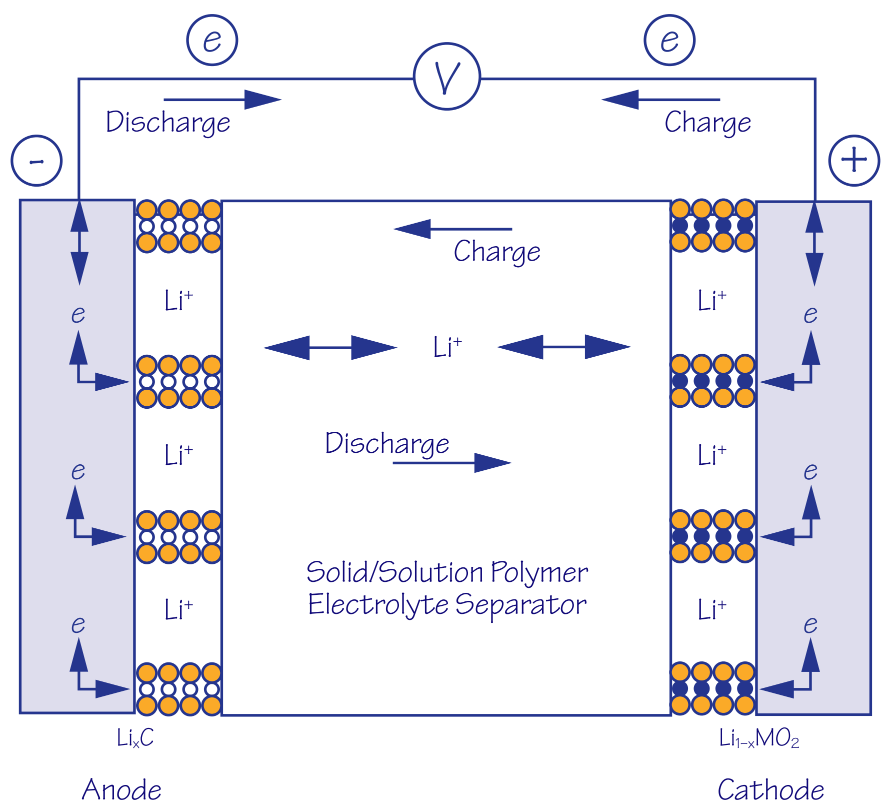
Solid/Solution Polymer Separators for Rechargeable Lithium Ion Batteries

Objective

The objective of this project is to develop an improved solid polymer electrolyte—with the conductivity of a liquid electrolyte but the solid properties of a polymer electrolyte—and to demonstrate its use in a rechargeable lithium battery.

Technical Challenge

Because most polymer electrolytes have poor ionic conductivities (between 10^{-6} and 10^{-4} S cm^{-1}), using secondary (rechargeable) polymer electrolyte lithium ion batteries in EVs and HEVs poses a significant challenge. The challenge is achieving enough energy density to provide an acceptable driving range and enough power density for adequate acceleration. In contrast, the conductivities of the liquid electrolytes used in liquid electrolyte lithium ion batteries are between 10^{-3} and 10^{-2} S cm^{-1}. Unfortunately, because liquid electrolytes require the use of a porous matrix, the separation between the electrodes must be greater than that for a solid polymer, so the batteries must be larger.



Lynntech, Inc.
7610 Eastmark Dr.
Suite 105
College Station, TX
77840

Contact
Alan Cisar
(409) 693-0017

Technical Concept/Approach

We will produce a solid solution of a lithium solvating solvent in a cation-conducting ionomer. This approach is similar to the gel electrolyte approach already demonstrated by some researchers, but with some significant advantages. The most fundamental of these is the use of an ionomer as the primary polymer. Because the ionomer already has anionic sites as part of its structure, there is no need to add salt to support conduction. A further advantage is that, with the anionic sites immobilized on the backbone of the polymer, only the lithium ions are mobile. This leads to a smaller cross section and greater mobility for the mobile species, which helps to improve conductivity. In addition, the fixed sites can never drift to either electrode and increase the internal resistance of the battery. The figure illustrates the function of a separator in a rechargeable lithium ion battery. This component, which consists of a polymer solution in the batteries described here, must be both an electronic insulator and a good lithium ion conductor.

Status

This project is in its initial stages. Preliminary work indicates that lithium ion conductivities in excess of 4×10^{-3} S cm^{-1} can be achieved in solid solution polymer electrolytes produced from ionomers by means of this approach.

Benefits

Development of this new polymer electrolyte will provide higher power and energy densities in rechargeable lithium ion batteries and in polymer-type lithium primary batteries. The new polymer electrolytes are also expected to improve the performance of a wide range of smaller lithium ion batteries, including those used in laptop computers, cellular phones, and camcorders.

CARAT

Topic Area 16

Ovonic Ni/MH Bipolar Battery for HEV Applications

Objective

Our objective is to develop a viable high-power bipolar module design with multicell construction using Ovonic's nickel metal hydride battery technology. We will also fabricate and test a prototype three-cell bipolar battery to verify the concept.

Technical Challenge

The technical challenges to successful technology development include finding a suitable current collector that provides a housing to contain the active material in the cell, developing an electrolyte leakproof seal, creating a low-pressure design, and identifying an efficient gas-management system.

Technical Concept/Approach

The proposed design will include self-contained electroactive material containers that will also serve as current collectors. The positive and negative electrode containers will be isolated by using plastic insulators. The insulators will house the seal that will prevent electrolyte leakage paths. There will be a separate gas-management system for all the cells that will keep gases out while preventing electrolyte loss.

Status

As the first task of the project, we are conducting a literature search on bipolar design, especially as it relates to alkaline cells. We have also begun prototype design work (on paper)—keeping in mind the practicality required for the design and the need to simplify the design to prevent potential production problems.

Benefits

The work described will provide a relatively low-capacity/high-power cell for HEV applications. The simplicity of the construction and elimination of intercell connections and current collection terminals are expected to lower the cost of producing these high-power cells.

Negative
Separator
Cooling Hole
+
Positive
3.6 volts
–
Gasket
Substrate Weld
Support Spacer
Access Hole
Inner Connect Weld

Ovonic Battery Company
1707 Northwood Dr.
Troy, MI 48084

Contact
S. Venkatesan, PhD
(248) 362-1750

Topic Area 16

High-Capacity Rechargeable Batteries Using Tin-Based Electrodes

Objective

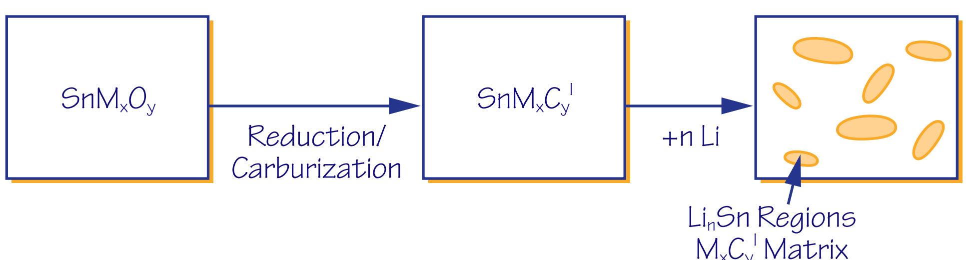
T/J Technologies will develop and characterize new, high-capacity anode materials for lithium ion batteries. We intend to prepare novel tin-metal oxide precursors based on early transition metals, convert the precursors into SnM_xC_y, demonstrate reversible capacities of 400 mAh/g or greater, and demonstrate irreversible capacities of 100 mAh/g or less.

Technical Challenge

Segregation of tin will be the critical challenge for successful technology development. Such segregation typically reduces battery capacity—as previously reported for other tin-based anode materials.

Technical Concept/Approach

We intend to eliminate tin segregation by dispersing the tin atoms within carbide matrices that are based on early transition metals. The proposed porous carbide matrices should inhibit movement of the tin atoms while permitting the lithium ions to readily diffuse (see figure), resulting in performance exceeding that of current state-of-the-art tin-based composite oxides (TCO). These materials will be evaluated by using standard electrochemical procedures and by using test procedures prescribed by PNGV and USABC. Tin aggregation will be minimal because the conductive lattice delivers electrons to the isolated tin regions, where they are required for tin/lithium alloying. The conductive lattice thus eliminates a driving force for tin aggregation. The carbide, which is more rigid than the TCO, maintains its mechanical integrity more readily than the TCO; this difference is evident in the mechanical hardness of about 30 GPa for nitrides and carbides, which far exceeds the hardness of most glasses. In addition, the activation energy of lithium diffusion can be selectively manipulated by adding appropriate transition metal dopants and/or choosing the appropriate sol-gel reaction conditions to enhance microstructure.



Status

In addition to the TCO materials first reported by Fujifilm, other groups have studied tin-based oxide electrodes. All groups have noted a rapid loss of capacity caused by tin aggregation and eventual fracture of the anode.

Benefits

The new, high-capacity anode materials developed during this project will improve the capacity and driving range for EV batteries.

T/J Technologies, Inc.

3850 Research Park Dr.
P.O. Box 215
Ann Arbor, MI 48106

Contact

Daryl G. Clerc, PhD
(734) 213-1637, ext. 20
Fax (734) 213-3758
tjclercd@aol.com